Global Positioning System (GPS) Standard Positioning Service (SPS) Performance Analysis Report

Submitted To

Federal Aviation Administration
GPS Product Team
AND 730
1284 Maryland Avenue SW
Washington, DC 20024

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Submitted by

William J. Hughes Technical Center
NSTB/WAAS T&E Team
ACB 430
Atlantic City International Airport, NJ 08405

EXECUTIVE SUMMARY

The GPS Product Team (AND 730) has tasked the Navigation Branch (ACB 430) at the William J. Hughes Technical Center to document Global Positioning System (GPS) Standard Positioning Service (SPS) performance in quarterly GPS Performance Analysis (PAN) Reports. The report contains the analysis performed on data collected at the following NSTB and Wide Area Augmentation System (WAAS) Reference Station locations: Atlantic City, Columbus, Denver, Grand Forks, Greenwood, Prescott, Anchorage (WAAS), Billings (WAAS), Chicago (WAAS), Kansas City (WAAS), Salt Lake City (WAAS), Miami (WAAS) and Atlanta (WAAS). This analysis verifies the GPS SPS performance as compared to the performance parameters stated in the SPS Specification Annex A.

This report, Report #42, includes data collected from 1 April through 30 June 2003. The next quarterly report will be issued 31 October 2003.

Analysis of this data includes the following categories: Coverage performance, Service Availability Performance, Position Performance, Range Performance and Solar Storm Effects on GPS SPS performance.

Coverage performance was based on Position Dilution of Precision (PDOP). Utilizing the weekly almanac posted on the US Coast Guard navigation web site, the coverage for every 5^{o} grid point between 180W to 180E and 80S and 80N was calculated for every minute over a 24-hour period for each of the weeks covered in the reporting period. For this reporting period, the coverage based on PDOP less than six for the CONUS was 98.542% or better.

Availability was verified by reviewing the "Notice: Advisory to Navstar Users" (NANU) reports issued between 1 April and 30 June 2003 and by calculating the satellite availability from the data obtained from the fourteen sites. A total of fourteen outages were reported in the NANU's. All of the outages were scheduled. The quarterly availabilities for all sites was 100%, with the exception of Anchorage at 99.998%. Each of these availabilities is within the SPS value of 99.85%. These availability percentages were calculated using DOP data collected at one-second intervals.

The statistics on the days of significant solar activity met all GPS Standard Positioning Service (SPS) specifications.

Position accuracies were verified by calculating the 95% and 99.99% values of horizontal and vertical errors. Range performance was verified for each satellite using the data collected from the NSTB Atlantic City site. The data was collected in one-second samples. All of the satellites met the range error specifications. The maximum range error recorded was 34.361 meters on Satellite PRN 11. The SPS specification states that the range error should never exceed 150 meters. The maximum range rate error recorded was 0.94641 Meters/second on Satellite PRN 5. The SPS specification states that the range rate error should never exceed 2 meters/second. The maximum range acceleration error recorded was 9.50 Millimeters/second^2 on Satellite PRN 5. The SPS specification states that the range acceleration error should never exceed 19 Millimeters/second^2.

The GLONASS/GPS performance section has been permanently removed from this report.

From the analysis performed on data collected between 1 April and 30 June 2003, the GPS performance met all SPS requirements that were evaluated. Although our data analysis showed no failures, there were two GPS satellite failures during this quarter that our data did not show due to the fact that the satellites were out of view at the time of the failure. Please refer to the problem report section for further details.

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1.0 Introduction

1.1 Objective of GPS SPS Performance Analysis Report

In 1993, the FAA began monitoring and analyzing Global Positioning System (GPS) Standard Positioning Service (SPS) performance data. At present, the FAA has approved GPS for IFR and is developing Wide Area Augmentation System (WAAS) and Local Area Augmentation (LAAS), both of which are GPS augmentation systems. In order to ensure the safe and effective use of GPS and its augmentation systems within the NAS, it is critical that characteristics of GPS performance as well as specific causes for service outages be monitored and understood. To accomplish this objective, GPS SPS performance data is documented in a quarterly GPS Analysis report. This report contains data collected at the following National Satellite Test Bed (NSTB) and WAAS reference station locations:

- Atlantic City, NJ
- Columbus, NE
- Denver, CO
- Grand Forks, ND
- Greenwood, MS
- Prescott, AZ
- Billings, MT
- Anchorage, AK
- Chicago, IL
- Kansas City, KS
- Salt Lake City, UT
- Miami, FL
- Atlanta, GA

(Future reports will include all WAAS sites but a database that can handle all that data needs to be developed. ACB 430 is in the process of setting up an Oracle database for this purpose.)

The analysis of the data is divided into the four performance categories stated in the Standard Positioning Service Performance Specification (SPS) Annex A (June 2, 1995). These categories are:

- Coverage Performance
- Satellite Availability Performance
- Service Reliability Standard
- Positioning, Ranging and Timing Accuracy Standard.

The results were then compared to the performance parameters stated in the SPS.

1.2 Summary of Performance Requirements and Metrics

Table 1-1 lists the performance parameters from the SPS and identifies those parameters verified in this report.

Appendix E Table 1.2 contains the performance parameters evaluated for the WAAS in this report.

1.3 Report Overview

Section 2 of this report summarizes the results obtained from the coverage calculation program called SPS_CoverageArea developed by ACB 430. The SPS_CoverageArea program uses the GPS satellite almanacs to compute each satellite position as a function of time for a selected day of the week. This program establishes a 5-degree grid between 180 degrees east and 180 degrees west, and from 80 degrees north and 80 degrees south. The program then computes the PDOP at each grid point (1485 total grid points) every minute for the entire day and stores the results. After the PDOP's have been saved the 99.99% index of 1-minute PDOP at each grid point is determined and plotted as contour lines (Figure 2-1). The program also saves the number of satellites used in PDOP calculation at each grid point for analysis.

Section 3 summarizes the GPS availability performance by providing the "Notice: Advisory to Navstar Users" (NANU) messages to calculate the total time of forecasted and actual satellite outages. This section also includes the maximum and minimum of the PDOP, HDOP and VDOP for each of the thirteen NSTB/WAAS sites.

Section 4 summarizes service reliability performance. It will be reported at the end of the first year of this analysis because the SPS standard is based a measurement interval of one year. Data for the quarter is provided for completeness.

Section 5 provides the position and repeatable accuracies based on data collected on a daily basis at one-second intervals. This section also provides the statistics on the range error, range error rate and range acceleration error for each satellite. The overall average, maximum, minimum and standard deviations of the range rates and accelerations are tabulated for each satellite.

In Section 6, the data collected during solar storms is analyzed to determine the effects, if any, of GPS SPS performance.

Appendix A provides a summary of all the results as compared to the SPS specification.

Appendix B provides the geomagnetic data used for Section 6.

Appendix C provides a PAN Problem Report.

Appendix D provides a glossary of terms used in this PAN report. This glossary was obtained directly from the GPS SPS specification document.

Table 1-1 SPS Performance Requirements

Coverage Standard	**Conditions and Constraints**	**Evaluated in This Report**
≥ 99.9% global average	• Probability of 4 or more satellites in view over any 24 hour interval, averaged over the globe • 4 satellites must provide PDOP of 6 or less • 5° mask angle with no obscura • Standard is predicated on 24 operational satellites, as the constellation is defined in the almanac	✓
≥ 96.9% at worst-case point	• Probability of 4 or more satellites in view over any 24 hour interval, for the worst-case point on the globe • 4 satellites must provide PDOP of 6 or less • 5° mask angle with no obscura • Standard is predicated on 24 operational satellites, as the constellation is defined in the almanac	✓
Satellite Availability Standard	**Conditions and Constraints**	
≥ 99.85% global average	• Conditioned on coverage standard • Standard based on a typical 24 hour interval, averaged over the globe • Typical 24 hour interval defined using averaging period of 30 days	✓
≥ 99.16% single point average	• Conditioned on coverage standard • Standard based on a typical 24 hour interval, for the worst-case point on the globe • Typical 24 hour interval defined using averaging period of 30 days	✓
≥ 95.87% global average on worst-case day	• Conditioned on coverage standard • Standard represents a worst-case 24 hour interval, averaged over the globe	✓
≥ 83.92% at worst-case point on worst-case day	• Conditioned on coverage standard • Standard based on a worst-case 24 hour interval, for the worst-case point on the globe	✓
Service Availability Standard	**Conditions and Constraints**	
≥ 99.97% global average	• Conditioned on coverage and service availability standards • 500 meter NTE predictable horizontal error reliability threshold • Standard based on a measurement interval of one year; average of daily values over the globe • Standard predicated on a maximum of 18 hours of major service failure behavior over the sample interval	✓

≥ 99.79% single point average	• Conditioned on coverage and service availability standards • 500 meter Not-to-Exceed (NTE) predictable horizontal error reliability threshold • Standard based on a measurement interval of one year; average of daily values from the worst-case point on the globe • Standard based on a maximum of 18 hours of major service failure behavior over the sample interval	✓
Accuracy Standard	Conditions and Constraints	
Predictable Accuracy ≤ 100 m horz. error 95% of time ≤ 156 m vert. error 95% of time ≤ 300 m horz. error 99.99% of time ≤ 500 m vert. error 99.99% of time	• Conditioned on coverage, service availability and service reliability standards • Standard based on a measurement interval of 24 hours, for any point on the globe	✓
Repeatable Accuracy ≤ 141 m horz. error 95% of time ≤ 221 m vert. error 95% of time	• Conditioned on coverage, service availability and service reliability standards • Standard based on a measurement interval of 24 hours, for any point on the globe	✓
Relative Accuracy ≤ 1.0 m horz. error 95% of time ≤ 1.5 m vert. error 95% of time	• Conditioned on coverage, service availability and service reliability standards • Standard based on a measurement interval of 24 hours, for any point on the globe • Standard presumes that the receivers base their position solutions on the same satellites, with position solutions computed at approximately the same time	Future Reports
Time Transfer Accuracy ≤ 340 nanoseconds time transfer error 95% of time	• Conditioned on coverage, service availability and service reliability standards • Standard based upon SPS receiver time as computed using the output of the position solution • Standard based on a measurement interval of 24 hours, for any point on the globe • Standard is defined with respect to Universal Coordinated Time, as it is maintained by the United States Naval Observatory	✓
Range Domain Accuracy ≤ 150 m NTE range error ≤ 2 m/s NTE range rate error ≤ 8 mm/s^2 range acceleration error 95% of time ≤ 19 mm/s^2 NTE range acceleration error	• Conditioned on satellite indicating healthy status • Standard based on a measurement interval of 24 hours, for any point on the globe • Standard restricted to range domain errors allocated to space/control segments • Standards are not constellation values -- each satellite is required to meet the standards • Assessment requires minimum of four hours of data over the 24 hour period for a satellite in order to evaluate that satellite against the standard	✓

2.0 Coverage Performance

Coverage: *The percentage of time over a specified time interval that a sufficient number of satellites are above a specified mask angle and provide an acceptable position solution geometry at any point on or near the Earth.*

Dilution of Precision (DOP): *A Root Mean Square (RMS) measure of the effects that any given position solution geometry has on position errors. Geometry effects may be assessed in the local horizontal (HDOP), local vertical (VDOP), three-dimensional position (PDOP), or time (TDOP) for example.*

Coverage Standard	Conditions and Constraints
≥ 99.9% global average	• Probability of 4 or more satellites in view over any 24 hour interval, averaged over the globe • 4 satellites must provide PDOP of 6 or less • 5° mask angle with no obscura • Standard is predicated on 24 operational satellites, as the constellation is defined in the almanac
≥ 96.9% at worst-case point	• Probability of 4 or more satellites in view over any 24 hour interval, for the worst-case point on the globe • 4 satellites must provide PDOP of 6 or less • 5° mask angle with no obscura • Standard is predicated on 24 operational satellites, as the constellation is defined in the almanac

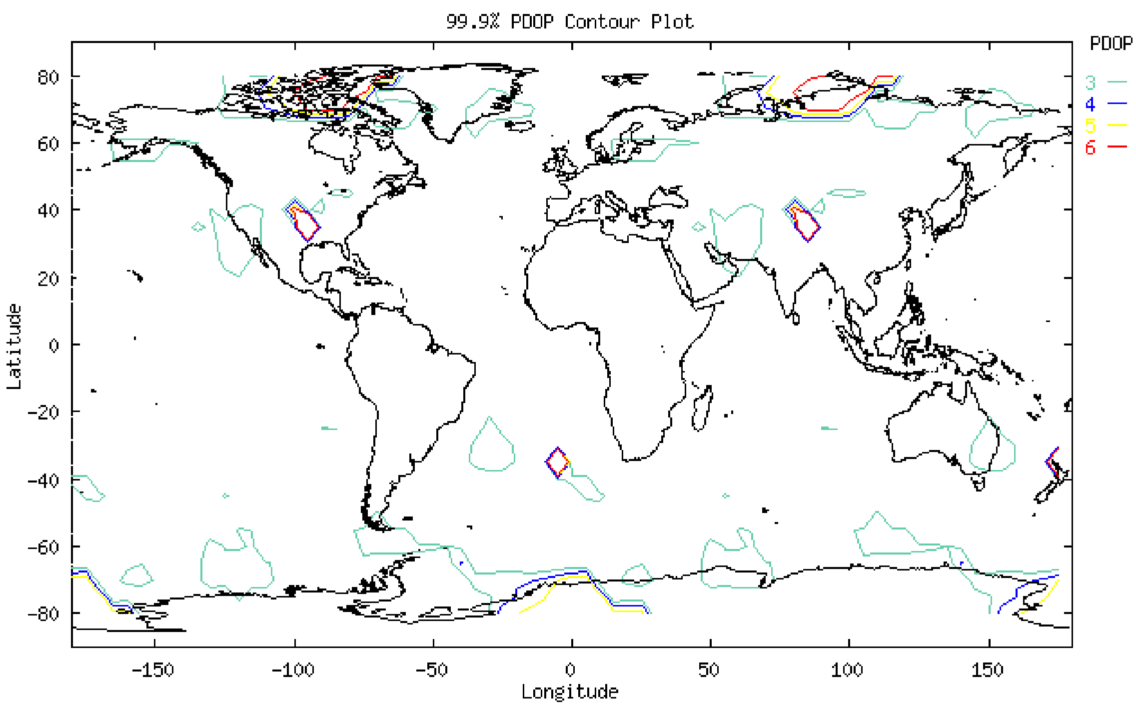
Almanacs for GPS weeks 149-162 used for this coverage portion of the report were obtained from the Coast Guard web site (www.navcen.uscg.mil). Using these almanacs, an SPS coverage area program developed by ACB 430 was used to calculate the PDOP at every 5^o point between longitudes of 180W to 180E and 80S and 80N at one-minute intervals. This gives a total of 1440 samples for each of the 2376 grid points in the coverage area. Table 2-1 provides the global averages and worst-case availability over a 24-hour period for each week. Table 2-1 also gives the global 99.9% PDOP value for each of the thirteen GPS Weeks. The PDOP was 3.850 or better 99.9% of the time for each of the 24-hour intervals.

The GPS coverage performance evaluated met the specifications stated in the SPS.

Table 2-1 Coverage Statistics

GPS Week	Global 99.9% PDOP Value*	Global Average* (Spec: ≥ 99.9%)	Worst-Case Point (Spec: ≥ 96.9%)
188	3.782	99.982	99.167
189	3.850	99.981	99.167
190	3.735	99.990	99.167
191	3.735	99.990	99.167
192	3.718	99.993	99.236
193	3.701	99.994	99.167
194	3.600	99.995	99.167
195	3.499	99.996	99.167
196	3.544	99.996	99.167
197	3.281	99.997	99.167
198	3.822	99.978	98.542
199	3.758	99.980	98.889
200	3.182	99.995	99.375

Figure 2-1 SPS Coverage (24-Hour Period: 9 June 2003)



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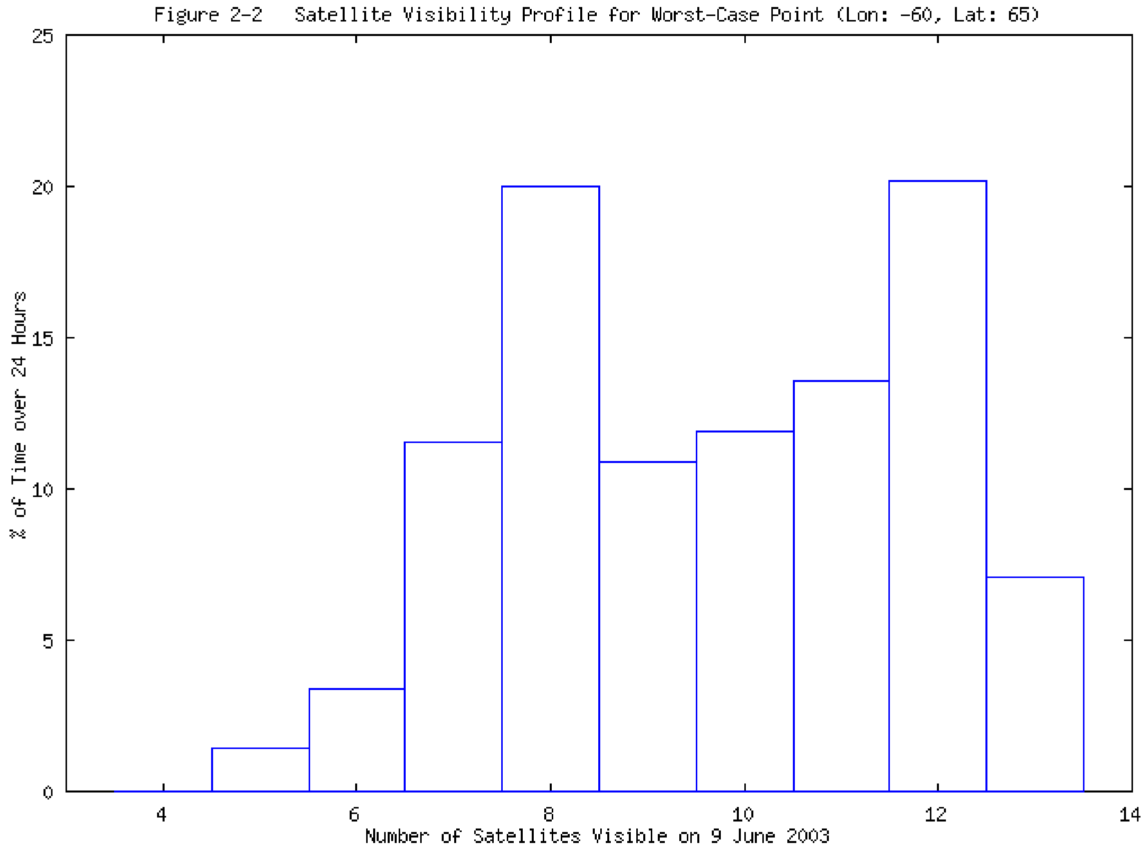


Figure 2-2 Satellite Visibility Profile for Worst-Case Point (Lon: -60, Lat: 65)
% of Time over 24 Hours
0
5
10
15
20
25
4
6
8
10
12
14
Number of Satellites Visible on 9 June 2003

3.0 Service Availability Performance

Service Availability: *Given coverage, the percentage of time over a specified time interval that a sufficient number of satellites are transmitting a usable ranging signal within view of any point on or near the Earth.*

3.1 Satellite Outages from NANU Reports

Satellite availability performance was analyzed based on published "Notice: Advisory to Navstar Users" messages (NANU's). During this reporting period, 1 April through 30 June 2003, there were a total of twenty-one reported outages. Seventeen of these outages were maintenance activities and were reported in advance. Four were unscheduled outages. A complete listing of outage NANU's for the reporting period is provided in Table 3-1. A complete listing of the forecasted outage NANU's for the reporting period can be found in Table 3-2. Canceled outage NANU's are provided in Table 3-3.

Table 3-1 NANUs Affecting Satellite Availability

NANU #	PRN	Type	Start Date	Start Time	End Date	End Time	Total Unscheduled	Total Scheduled	Total
2003034	2	S	3-Apr	19:47	4-Apr	6:43		10.93	10.93
36	3	S	9-Apr	22:55	10-Apr	2:06		3.18	3.18
40	17	S	17-Apr	21:21	18-Apr	5:01		7.67	7.67
41	27	S	22-Apr	3:09	22-Apr	7:00		3.85	3.85
46	30	S	30-Apr	14:37	30-Apr	22:48		8.18	8.18
48	11	S	1-May	22:29	2-May	4:39		6.17	6.17
49	26	S	8-May	21:35	9-May	2:23		4.80	4.80
51	23	S	22-May	21:49	23-May	0:45		2.93	2.93
55	23	S	27-May	21:25	28-May	5:23		7.97	7.97
56	27	S	26-May	17:33	29-May	21:15		3.70	3.70
57	3	S	30-May	4:52	30-May	10:49		5.95	5.95
59	5	S	2-Jun	15:18	9-Jun	14:17		166.98	166.98
61	5	S	11-Jun	20:19	13-Jun	20:52		24.55	24.55
70	17	S	26-Jun	19:42	1-Jul	0:00		100.20	100.20
Total Actual Unscheduled and Scheduled Downtime and Total Actual Downtime							**0.00**	**357.06**	**357.06**
Type:	S = Scheduled		U = Unscheduled						

There were multiple NANU's that were not listed in any of the charts. They are as follows:

NANU 35: Announced the launch of PRN21 on 31 March 2003.

NANU 38: Set PRN21 to usable status as of 5:27 Zulu on 12 April 2003.

NANU's 62-69: These NANU's pertain to next quarter's data. The delayed NANU #70 was the last NANU to pertain to this quarter's data. The duration of downtime for NANU #70 extended well into July. However, since statistics are only compiled relative to the quarter, the end time for that NANU equals the corresponding time of the end of the quarter.

	Table 3-2 NANUs Forecasted to Affect Satellite Availability							
NANU #	PRN	Type	Start Date	Start Time	End Date	End Time	Total	Comments
2003032	2	F	3-Apr	19:15	4-Apr	7:15	12	See NANU 34
33	3	F	9-Apr	22:45	10-Apr	10:45	12	See NANU 36
37	17	F	17-Apr	21:15	18-Apr	9:15	12	See NANU 40
39	27	F	22-Apr	3:00	22-Apr	15:00	12	See NANU 41
42	30	F	30-Apr	13:00	1-May	1:00	12	See NANU 46
43	11	F	1-May	22:00	2-May	10:00	12	See NANU 48
44	22	F	24-Apr	20:45	N/A	N/A	N/A	See NANU 45
47	26	F	8-May	21:00	9-May	9:00	12	See NANU 49
50	23	F	22-May	21:15	23-May	9:15	12	See NANU 51
52	23	F	27-May	21:00	28-May	9:00	12	See NANY 55
53	3	F	30-May	4:30	30-May	16:30	12	See NANU 57
54	27	F	26-May	17:33	N/A	N/A	N/A	See NANU 56
58	5	F	2-Jun	15:18	N/A	N/A	N/A	See NANU 59
60	5	F	11-Jun	20:19	N/A	N/A	N/A	See NANU 61
63	17	F	26-Jun	19:42	N/A	N/A	N/A	
					Total Forecast Downtime		**120**	

	Table 3-3 NANUs Canceled				
NANU#	PRN	Type	Start Date	Start Time	Comments
2003045	22	C	24-Apr	20:45	See NANU 44

Satellite Reliability, Maintainability, and Availability (RMA) data is being collected based on published "Notice: Advisory to Navstar Users" messages (NANU's). This data has been summarized in Table 3-4. The "Total Satellite Observed MTTR" was calculated by taking the average downtime of all satellite outage occurrences. Schedule downtime was forecasted in advance via NANU's. All other downtime reported via NANU was considered unscheduled. The "Percent Operational" was calculated based on the ratio of total actual operating hours to total available operating hours for every satellite.

Table 3-4 GPS Block II/IIA Satellite RMA Data		
Satellite Reliability/Maintainability/Availability (RMA) Parameter	**1 April - 30 Jun. 2003**	**1 October, 1999- 31 Mar. 2003**
Total Forecast Downtime (hrs):	120	3872.25
Total Actual Downtime (hrs):	357.06	6472.69
Total Actual Scheduled Downtime (hrs):	357.06	3548.68
Total Actual Unscheduled Downtime (hrs):	0	2924.01
Total Satellite Observed MTTR (hrs):	25.50	24.52
Scheduled Satellite Observed MTTR (hrs):	25.50	16.35
Unscheduled Satellite Observed MTTR (hrs):	N/A	62.21
# Total Satellite Outages:	14	264
# Scheduled Satellite Outages:	14	217
# Unscheduled Satellite Outages:	0	47
Percent Operational -- Scheduled Downtime:	99.42	99.61
Percent Operational -- All Downtime:	99.96	99.29

3.2 Service Availability

Service Availability Standard	Conditions and Constraints
≥ 99.85% global average	• Conditioned on coverage standard • Standard based on a typical 24 hour interval, averaged over the globe • Typical 24 hour interval defined using averaging period of 30 days
≥ 99.16% single point average	• Conditioned on coverage standard • Standard based on a typical 24 hour interval, for the worst-case point on the globe • Typical 24 hour interval defined using averaging period of 30 days
≥ 95.87% global average on worst-case day	• Conditioned on coverage standard • Standard represents a worst-case 24 hour interval, averaged over the globe
≥ 83.92% at worst-case point on worst-case day	• Conditioned on coverage standard • Standard based on a worst-case 24 hour interval, for the worst-case point on the globe

To verify availability, the data collected from receivers at the nine NSTB/WAAS sites was reduced to calculate DOP information and reported in Tables 3-5 to 3-7. The data was collected at one-second intervals between 1 April and 30 June 2003.

Table 3-5 PDOP Statistics

NSTB/WAAS Site	Min PDOP	Max PDOP	VDOP at Max PDOP	Mean PDOP	99.99% PDOP	99.99% VDOP	Number of Samples
Atlantic City	1.169	5.881	5.121	1.792	3.939	3.566	7214484
Columbus	1.167	5.028	4.405	1.817	4.630	3.601	7859189
Denver	1.165	5.768	5.198	1.833	4.681	3.568	7532621
Grand Forks	1.161	5.916	2.222	1.805	4.564	3.823	7717661
Greenwood	1.252	4.887	3.014	1.826	3.849	3.206	7673845
Prescott	1.246	5.999	5.732	2.210	5.971	5.704	6603396
Billings	1.178	5.996	4.848	1.802	4.596	3.801	7639414
Anchorage	1.146	7.460	7.109	1.807	5.182	4.434	7724207
Chicago	1.194	5.997	5.691	1.742	4.821	4.227	7712517
Kansas City	1.158	4.691	4.451	1.784	4.653	3.509	7697175
Salt Lake City	1.180	5.709	5.260	1.836	4.052	3.367	7517306
Miami	1.175	5.888	5.740	1.796	4.503	4.244	7715994
Atlanta	1.233	5.999	5.551	1.798	4.647	4.251	7699815

Tables 3-6 and 3-7 show the statistics related to maximum PDOP and PDOP greater than six, respectively. Table 3-6 shows the PDOP statistics for the worst-case point on the worst-case day.
NOTE: Global in this report refers to the fourteen sites used. Although future reports will have all additional sites, a true global availability cannot be determined since there aren't reference stations around the world.

Whenever the PDOP goes above six and an SPS requirement is not met, an investigation is performed to determine what caused the PDOP to go above six. The following is a list of programs/procedures used during times of high PDOP:

- Notice of Advisory to Navstar Users (NANU's) messages are used to verify that satellite outages did occur. (See Section 3.1 for more details about NANU's for this quarter.)

- A satellite outage detection program developed by ACB 430 verifies satellite outages that are not verified through a NANU. For example, a satellite outage can occur for just a few seconds during an upload. This satellite detection program monitors all the receivers and keeps track of what satellites the receiver should be tracking versus what satellites the receiver is actually tracking. At least six receivers need to be tracking the satellite prior to the outage and no receiver can be tracking the satellite for the program to detect an outage. This program is also being enhanced so that false locks and late ephemeris problems can also be detected. This program will also output flags from the receivers so that problems with the receiver or TRS software, if any, can be tracked more easily.

- Data from co-located receivers is analyzed for times that the PDOP goes above six. This helps in determining whether the problem is due to the environment.

The instance of worst performance where the PDOP went above six is reported in Table 3-6. The column labeled "NANU/SOD" reports whether the outage was detected via a NANU or the Satellite Outage Detection (SOD) program along with the Satellite PRN number that had the outage.

Table 3-6 Maximum PDOP Statistics

Site	GPS Week/ Day	Max PDOP	Number of Seconds of Whole Day PDOP > 6	NANU/SOD, Satellite PRN Number	Number of Samples	Availability on days when PDOP > 6
Anchorage	192	7.460	182		86121	99.789%
Worst-Case Point on Worst-Case Day = 99.789% (SPS Spec. $\geq$ 83.92%)						

Global Average on Worst-Case Day = 99.984% (SPS Spec. $\geq$ 95.87%)

Table 3-7 PDOP > 6 Statistics

NSTB/WAAS Site	Total Number of Seconds of PDOP Monitoring	Total Seconds with PDOP > 6	Overall % Availability
Atlantic City	7214484	0	100%
Columbus	7859189	0	100%
Denver	7532621	0	100%
Grand Forks	7717661	0	100%
Greenwood	7673845	0	100%
Prescott	6603396	0	100%
Billings	7639414	0	100%
Anchorage	7724207	182	99.998%
Chicago	7712517	0	100%
Kansas City	7697175	0	100%
Salt Lake City	7517306	0	100%
Miami	7715994	0	100%
Atlanta	7699815	0	100%
Worst Single Point Average = 99.998% (SPS Spec. $\geq$ 99.16%)			

Global Average over Reporting Period = 100% (SPS Spec. > 99.85%)

4.0 Service Reliability Standard

Service Reliability: *Given coverage and service availability, the percentage of time over a specified time interval that the instantaneous predictable horizontal error is maintained within a specified threshold at any point on or near the Earth.*

Service Reliability Standard	Conditions and Constraints
≥ 99.97% global average	• Conditioned on coverage and service availability standards • 500 meter NTE predictable horizontal error reliability threshold • Standard based on a measurement interval of one year; average of daily values over the globe • Standard predicated on a maximum of 18 hours of major service failure behavior over the sample interval
≥ 99.79% single point average	• Conditioned on coverage and service availability standards • 500 meter Not-to-Exceed (NTE) predictable horizontal error reliability threshold • Standard based on a measurement interval of one year; average of daily values from the worst-case point on the globe • Standard based on a maximum of 18 hours of major service failure behavior over the sample interval

Table 4-1 has the 99.99% horizontal errors reported by a receiver at each of the fourteen NSTB/WAAS sites. This will be evaluated against the SPS specification at the end of the year.

Table 4-1 Service Reliability Based on Horizontal Error

NSTB/WAAS Site	Number of Samples This Quarter	Maximum Horizontal Error (Meters)
Atlantic City	7214484	20.1
Columbus	7859189	20.8
Denver	7532621	14.9
Grand Forks	7717661	17.1
Greenwood	7673845	17.7
Prescott	6603396	13.9
Billings	7639414	21.7
Anchorage	7724207	20.6
Chicago	7712517	20.3
Kansas City	7697175	23.7
Salt Lake City	7517306	11.5
Miami	7715994	19.1
Atlanta	7699815	26.2

5.0 Accuracy Characteristics

***Accuracy:** Given coverage, service availability and service reliability, the percentage of time over a specified time interval that the difference between the measured and expected user position or time is within a specified threshold at any point on or near the Earth.*

Accuracy Standard	Conditions and Constraints
Predictable Accuracy ≤ 100 meters horizontal error 95% of time ≤ 156 meters vertical error 95% of time ≤ 300 meters horizontal error 99.99% of time ≤ 500 meters vertical error 99.99% of time	• Conditioned on coverage, service availability and service reliability standards • Standard based on a measurement interval of 24 hours, for any point on the globe
Repeatable Accuracy ≤ 141 meters horizontal error 95% of time ≤ 221 meters vertical error 95% of time	• Conditioned on coverage, service availability and service reliability standards • Standard based on a measurement interval of 24 hours, for any point on the globe
Relative Accuracy ≤ 1.0 meters horizontal error 95% of time ≤ 1.5 meters vertical error 95% of time	• Conditioned on coverage, service availability and service reliability standards • Standard based on a measurement interval of 24 hours, for any point on the globe • Standard presumes that the receivers base their position solutions on the same satellites, with position solutions computed at approximately the same time
Time Transfer Accuracy ≤ 340 nanoseconds time transfer error 95% of time	• Conditioned on coverage, service availability and service reliability standards • Standard based upon SPS receiver time as computed using the output of the position solution • Standard based on a measurement interval of 24 hours, for any point on the globe • Standard is defined with respect to Universal Coordinated Time, as it is maintained by the United States Naval Observatory
Range Domain Accuracy ≤ 150 meters NTE range error ≤ 2 meters/second NTE range rate error ≤ 8 millimeters/second^2 range acceleration error 95% of time ≤ 19 millimeters/second^2 NTE range acceleration error	• Conditioned on satellite indicating healthy status • Standard based on a measurement interval of 24 hours, for any point on the globe • Standard restricted to range domain errors allocated to space/control segments • Standards are not constellation values -- each satellite is required to meet the standards • Assessment requires minimum of four hours of data over the 24 hour period for a satellite in order to evaluate that satellite against the standard

5.1 Position Accuracies

The data used for this section was collected for every second between 1 April through 30 June 2003 at the NSTB and WAAS selected locations.

Table 5-1 provides the 95% and 99.99% horizontal and vertical error accuracies for the quarter.

Table 5-1 Horizontal & Vertical Accuracy Statistics for the Quarter

NSTB Site	95% Horizontal (Meters)	95% Vertical (Meters)	99.99% Horizontal (Meters)	99.99% Vertical (Meters)
Atlantic City	4.535	7.040	17.024	17.039
Columbus	4.490	7.156	19.018	18.251
Denver	4.546	7.113	13.995	18.831
Grand Forks	4.103	6.255	10.510	17.052
Greenwood	5.035	8.252	15.261	20.667
Prescott	4.935	8.220	9.476	24.749
Billings	4.275	6.294	12.281	15.862
Anchorage	3.610	6.153	7.559	15.539
Chicago	4.551	6.953	14.596	18.867
Kansas City	4.736	7.409	20.098	19.903
Salt Lake City	4.605	7.143	10.758	19.624
Miami	5.608	10.437	15.534	23.768
Atlanta	5.039	7.959	16.226	21.526

Figures 5-1 and 5-2 are the combined histograms of the vertical and horizontal errors for all fourteen NSTB and WAAS sites from 1 April to 30 June 2003.

Figure 5-1 Combined Vertical Error Histogram

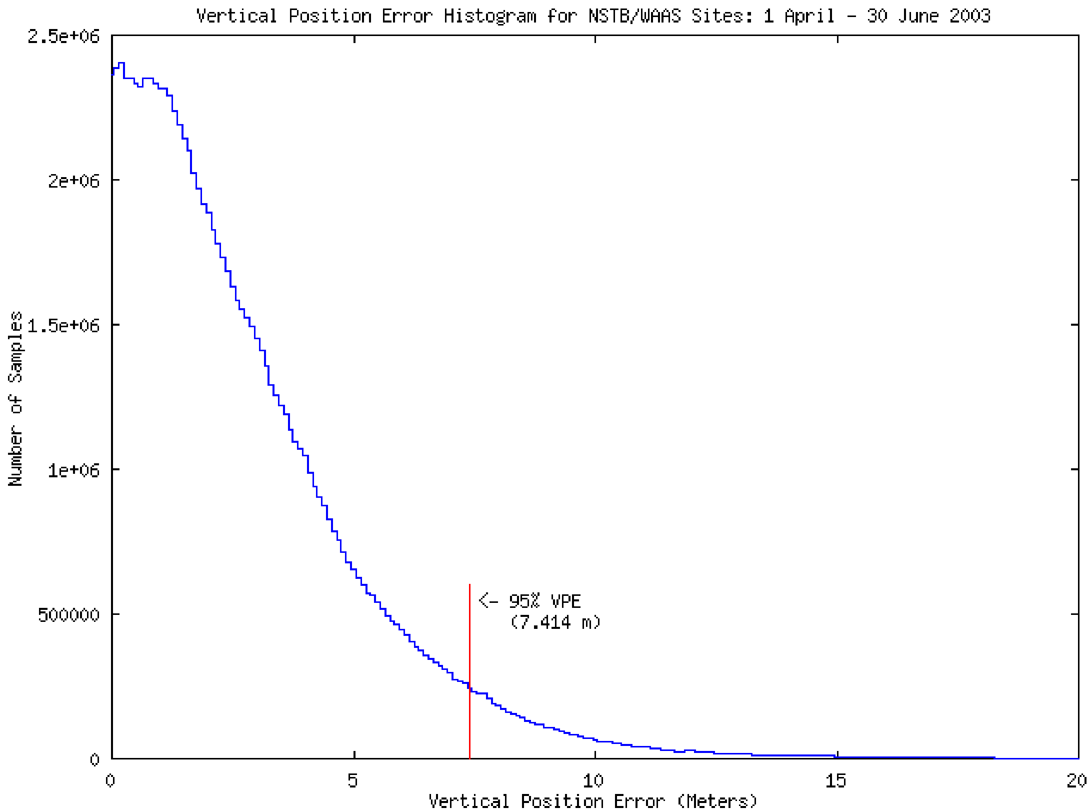
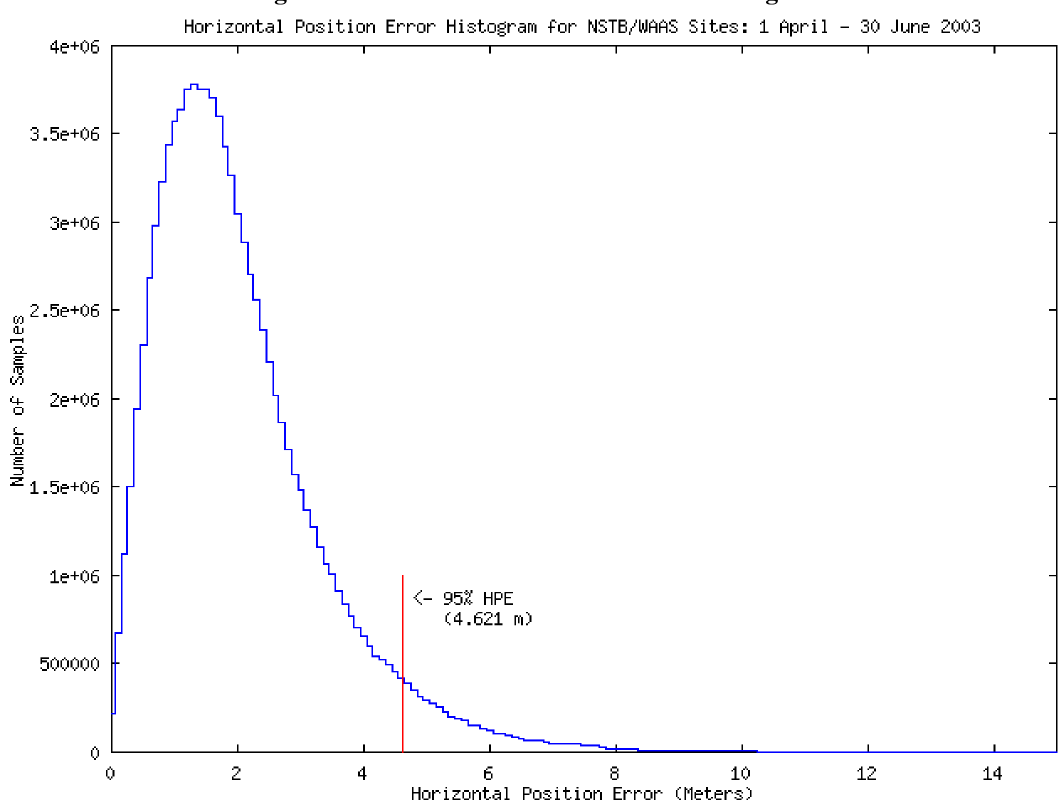


Figure 5-2 Combined Horizontal Error Histogram



5.2 Repeatable Accuracy

Table 5-2 provides the repeatability statistics, which met all of the evaluated requirements stated in the SPS.

Table 5-2 Repeatability Statistics

NSTB Site	95% Horizontal (m)	95% Vertical (m)
Atlantic City	1.737	3.984
Columbus	1.964	5.756
Denver	1.851	4.953
Grand Forks	1.585	4.763
Greenwood	2.079	5.599
Prescott	1.946	6.165
Billings	1.834	4.159
Anchorage	1.370	4.744
Chicago	1.965	4.909
Kansas City	2.051	5.893
Salt Lake City	2.187	5.603
Miami	1.967	6.137
Atlanta	1.828	5.550

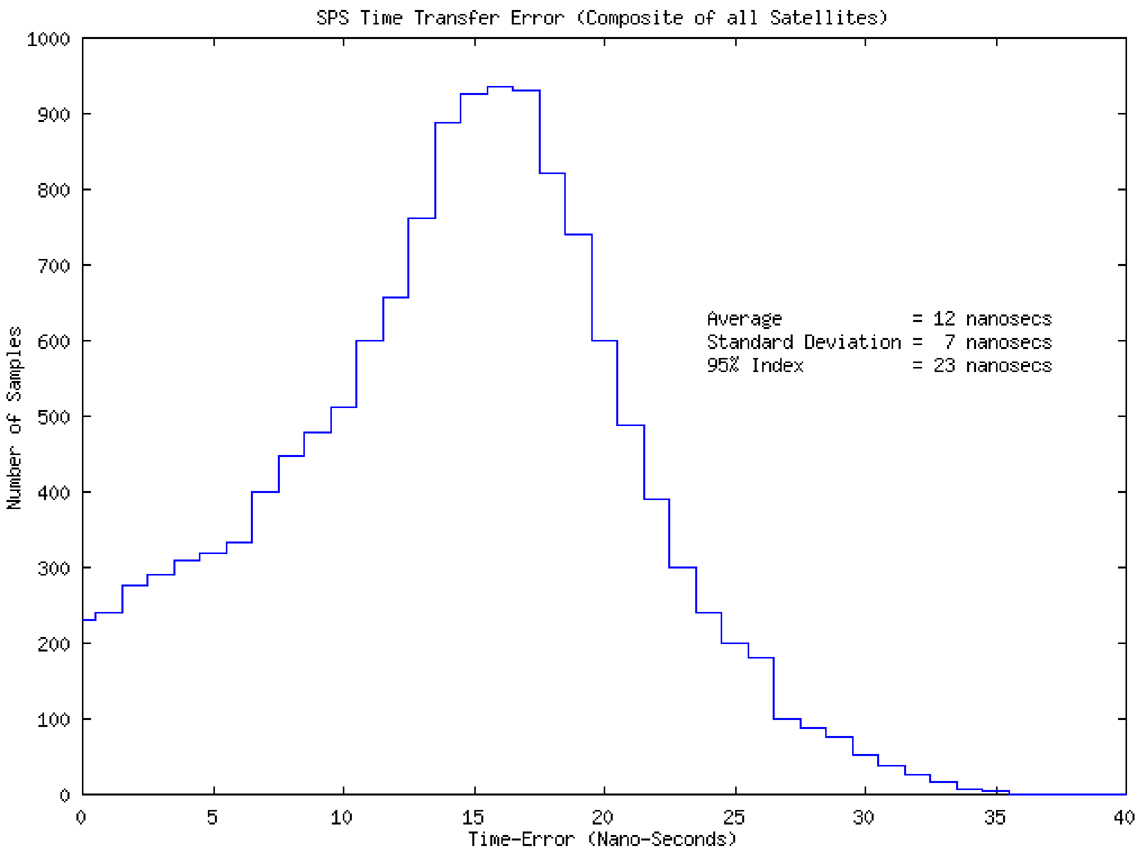
5.3 Relative Accuracy

To be included in future reports.

5.4 Time Transfer Accuracy

The GPS time error data between 1 April and 30 June 2003 was down loaded from USNO Internet site. The USNO data file contains the time difference between the USNO master clock and GPS system time for each GPS satellites during the time period. Over 10,000 samples of GPS time error are contained in the USNO data file. In order to evaluate the GPS time transfer error, the data file was used to create a histogram (Fig 5-3) to represent the distribution of GPS time error. The histogram was created by taking the absolute value of time difference between the USNO master clock and GPS system time, then creating data bins with one nanosecond precision. The number of samples in each bin was then plotted to form the histogram in Fig 5-3. The mean, standard deviation, and 95% index are within the requirements of GPS SPS time error.

Figure 5-3 Time Transfer Errors



5.5 Range Domain Accuracy

Tables 5-3 through 5-5 provide the statistical data for the range error, range rate error and the range acceleration error for each satellite. This data was collected between 1 April and 30 June 2003. The Millennium at Anderson was used to collect range measurement. Future PAN reports will contain statistics from all WAAS sites.

A weighted average filter was used for the calculation of the range rate error and the range acceleration error. All Range Domain SPS specifications were met.

Table 5-3 Range Error Statistics (meters)

PRN	Range Error Mean	Range Error RMS	1σ	95% Range Error	Max Range Error (SPS Spec. ≤ 150 m)	Samples
1	0.217	2.571	2.562	5.115	19.959	2051293
2	1.085	2.599	2.362	5.124	19.003	2052171
3	0.813	2.394	2.252	4.532	23.225	1615960
4	-0.299	3.141	3.127	6.401	15.182	1977354
5	-0.478	3.492	3.459	6.683	27.355	2059645
6	-1.151	3.630	3.443	6.815	19.324	2200926
7	0.253	2.782	2.770	5.740	13.423	2086925
8	-0.069	2.780	2.779	5.479	19.667	1972334
9	-0.684	3.236	3.163	6.227	15.557	2058518
10	0.508	4.053	4.022	8.146	15.571	1863287
11	0.399	2.566	2.535	4.607	34.361	1958530
13	-0.449	2.179	2.132	4.523	16.312	2236973
14	-0.021	2.781	2.781	5.352	14.176	2053112
15	0.422	3.286	3.259	6.741	25.207	2035610
16	0.396	2.097	2.060	4.155	21.436	1856119
17	-0.174	3.996	3.992	7.595	20.250	1702831
18	-0.490	3.318	3.281	6.414	18.682	1929046
20	0.388	2.944	2.919	5.126	31.821	2331268
21	-0.756	3.768	3.691	7.533	13.752	1418258
23	0.423	3.580	3.555	6.796	18.093	1892078
24	-0.274	3.751	3.741	7.395	16.308	2060962
25	-0.068	2.730	2.729	5.564	11.589	2068410
26	-0.888	3.979	3.879	7.436	21.250	1621691
27	-0.248	1.946	1.930	3.794	11.339	1592709
28	0.677	2.854	2.773	5.948	15.830	1856636
29	-0.595	4.032	3.988	7.420	15.793	1589777
30	-0.647	2.922	2.850	5.465	26.248	2226181
31	1.369	2.496	2.087	4.605	19.274	1729110

Table 5-4 Range Rate Error Statistics (meters/second)

PRN	Range Rate Error Mean	Range Rate Error RMS	Range Rate Error 1σ	95% Range Rate Error	Max Range Rate Error (SPS Spec. ≤ 2 m)	Samples
1	-0.00009	0.00535	0.00535	0.00358	0.61072	2051293
2	-0.00007	0.00265	0.00265	0.00326	0.19317	2052171
3	-0.00011	0.00304	0.00303	0.00324	0.23556	1615960
4	-0.00007	0.00557	0.00557	0.00487	0.57442	1977354
5	-0.00002	0.00760	0.00760	0.00528	0.94641	2059645
6	0.00003	0.00580	0.00580	0.00447	0.40540	2200926
7	0.00016	0.00425	0.00425	0.00430	0.33556	2086925
8	0.00006	0.00594	0.00594	0.00409	0.55834	1972334
9	-0.00012	0.00597	0.00596	0.00535	0.51286	2058518
10	-0.00020	0.00623	0.00623	0.00551	0.45323	1863287
11	-0.00005	0.00331	0.00331	0.00402	0.36386	1958530
13	-0.00021	0.00525	0.00524	0.00437	0.56146	2236973
14	0.00003	0.00365	0.00365	0.00414	0.45169	2053112
15	0.00011	0.00466	0.00466	0.00493	0.44140	2035610
16	-0.00008	0.00174	0.00174	0.00316	0.06368	1856119
17	0.00004	0.00627	0.00627	0.00589	0.54973	1702831
18	0.00005	0.00542	0.00542	0.00540	0.48327	1929046
20	-0.00018	0.00472	0.00472	0.00421	0.86012	2331268
21	0.00011	0.00588	0.00588	0.00603	0.36770	1418258
23	0.00005	0.00505	0.00505	0.00514	0.43389	1892078
24	-0.00005	0.00608	0.00608	0.00499	0.50909	2060962
25	-0.00003	0.00284	0.00284	0.00369	0.32757	2068410
26	-0.00033	0.00604	0.00603	0.00588	0.51443	1621691
27	0.00020	0.00254	0.00253	0.00344	0.34742	1592709
28	0.00008	0.00335	0.00335	0.00391	0.31005	1856636
29	-0.00030	0.00640	0.00639	0.00579	0.43932	1589777
30	-0.00002	0.00643	0.00643	0.00483	0.55753	2226181
31	-0.00014	0.00241	0.00241	0.00331	0.17835	1729110

Table 5-5 Range Acceleration Error Statistics (meters/second^2)

PRN	Range Acceleration Error Mean	Range Acceleration Error RMS	Range Acceleration 1σ	% ≤ 0.008 (SPS Spec. 95% of Time)	Max Range Acceleration Error (SPS Spec. ≤ 0.019 m/s2)	Samples
1	0	0.00005	0.00005	100	0.00611	2051293
2	0	0.00002	0.00002	100	0.00192	2052171
3	0	0.00003	0.00003	100	0.00235	1615960
4	0	0.00005	0.00005	100	0.00576	1977354
5	0	0.00007	0.00007	99.999	0.00950	2059645
6	0	0.00005	0.00005	100	0.00407	2200926
7	0	0.00004	0.00004	100	0.00336	2086925
8	0	0.00005	0.00005	100	0.00559	1972334
9	0	0.00005	0.00005	100	0.00514	2058518
10	0	0.00005	0.00005	100	0.00454	1863287
11	0	0.00003	0.00003	100	0.00364	1958530
13	0	0.00005	0.00005	100	0.00563	2236973
14	0	0.00003	0.00003	100	0.00450	2053112
15	0	0.00004	0.00004	100	0.00439	2035610
16	0	0.00001	0.00001	100	0.00062	1856119
17	0	0.00005	0.00005	100	0.00551	1702831
18	0	0.00005	0.00005	100	0.00481	1929046
20	0	0.00004	0.00004	99.999	0.00862	2331268
21	0	0.00005	0.00005	100	0.00368	1418258
23	0	0.00004	0.00004	100	0.00432	1892078
24	0	0.00005	0.00005	100	0.00508	2060962
25	0	0.00002	0.00002	100	0.00326	2068410
26	0	0.00005	0.00005	100	0.00513	1621691
27	0	0.00002	0.00002	100	0.00347	1592709
28	0	0.00003	0.00003	100	0.00311	1856636
29	0	0.00006	0.00006	100	0.00438	1589777
30	0	0.00006	0.00006	100	0.00559	2226181
31	0	0.00002	0.00002	100	0.00177	1729110

Figures 5-4, 5-5 and 5-6 are graphical representations of the distributions of the maximum range error, range rate error and range acceleration error for all satellites. None of the range errors for any of the satellites exceeded the 150-meter SPS requirement. The highest maximum range error occurred on satellite 11 with an error of 34.361 meters. Satellite 27 had the lowest maximum range error of 11.339 meters.

Figure 5-4 Distribution of Daily Max Range Errors

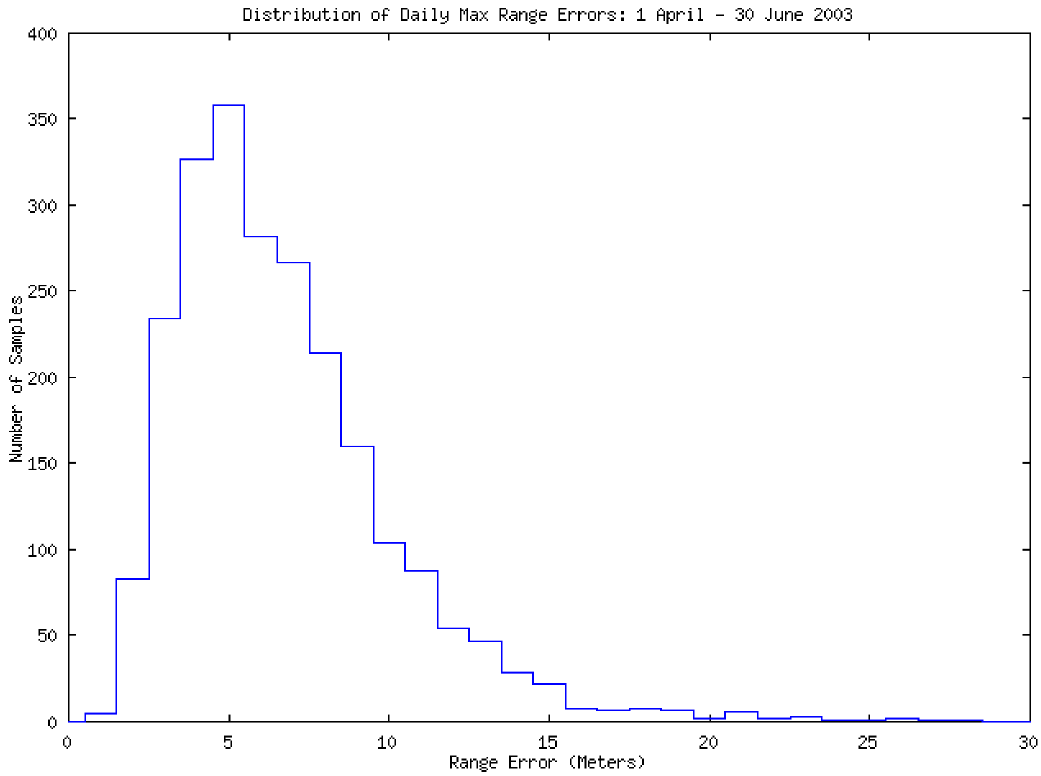


Figure 5-5: Distribution of Daily Max Range Rate Errors

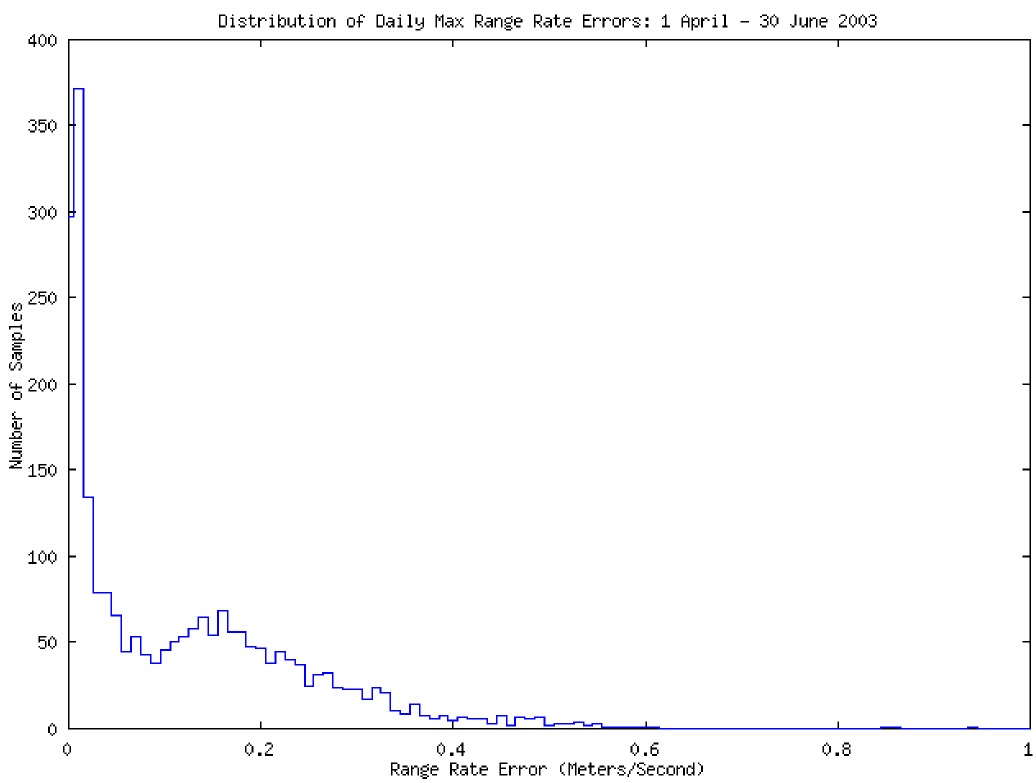


Figure 5-6: Distribution of Daily Max Acceleration Rate Errors

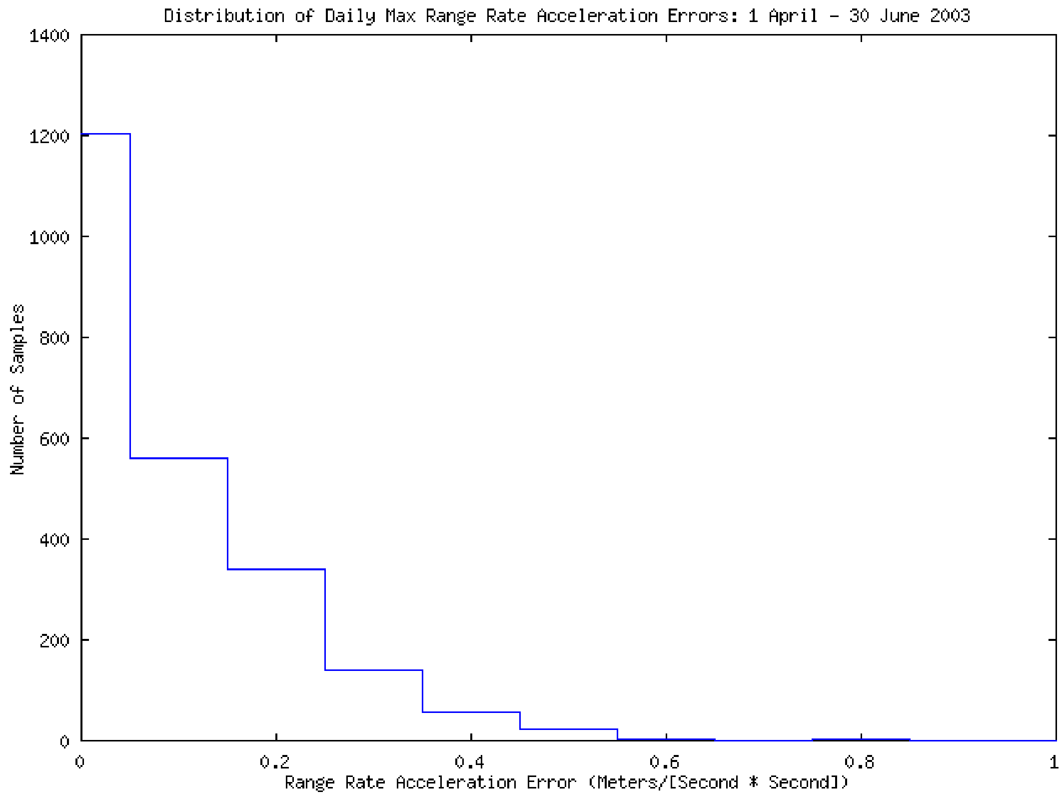
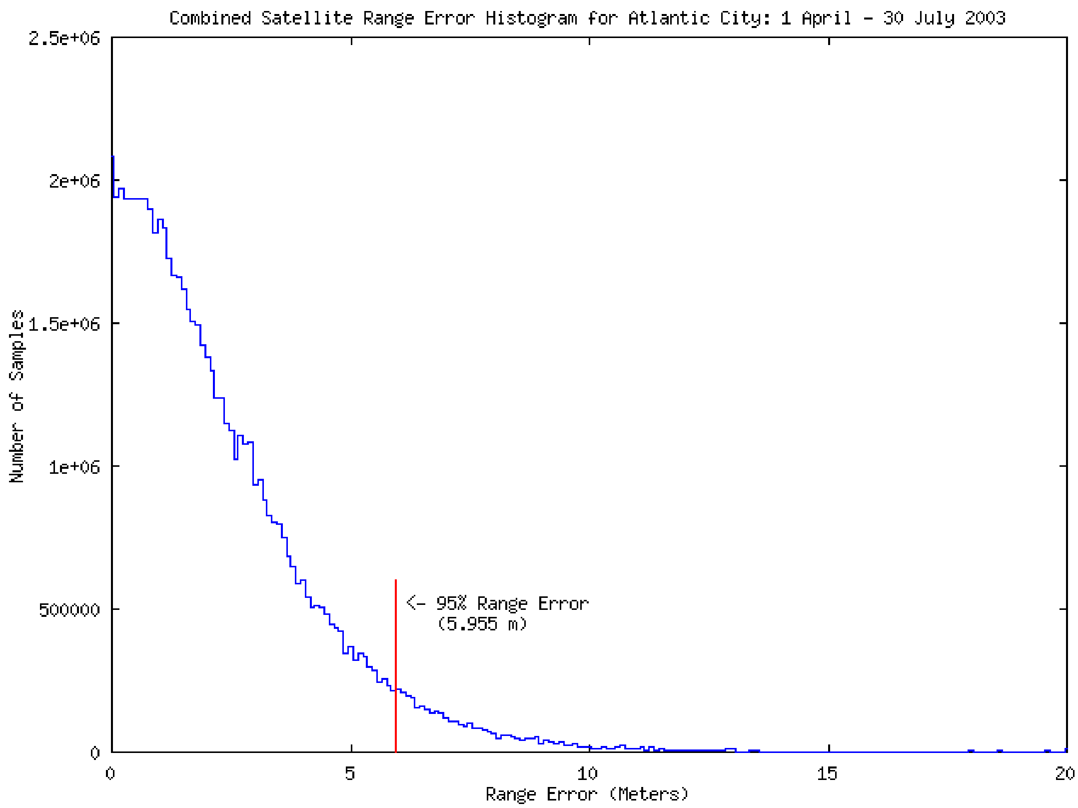


Figure 5-7: Range Error Histogram


Combined Satellite Range Error Histogram for Atlantic City: 1 April - 30 July 2003
Number of Samples
Range Error (Meters)
<- 95% Range Error
(5.955 m)
2.5e+06
2e+06
1.5e+06
1e+06
500000
0
0
5
10
15
20

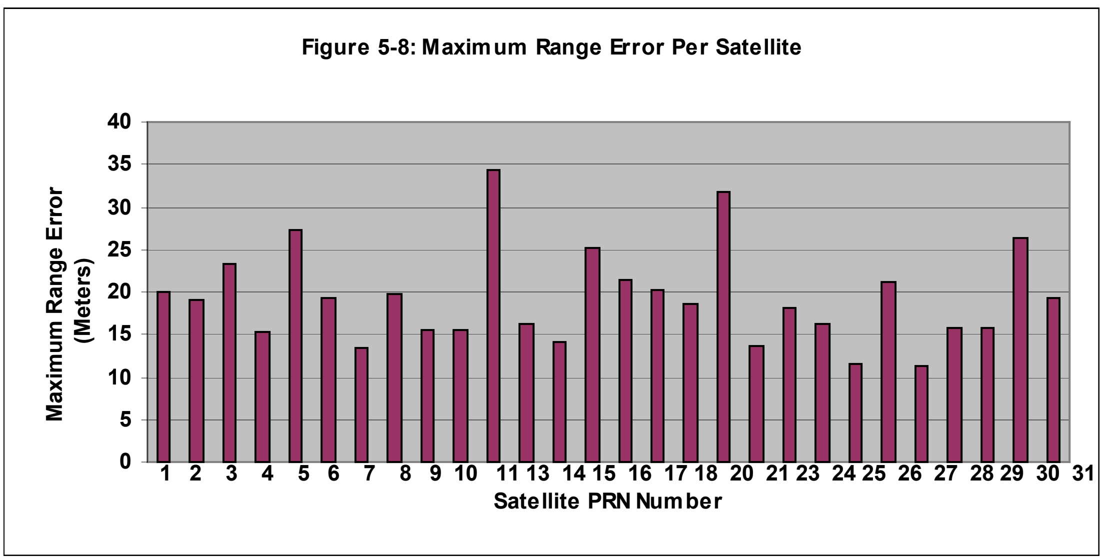


Figure 5-8: Maximum Range Error Per Satellite
Maximum Range Error (Meters)
Satellite PRN Number
40
35
30
25
20
15
10
5
0
1 2 3 4 5 6 7 8 9 10 11 13 14 15 16 17 18 20 21 23 24 25 26 27 28 29 30 31

Figure 5-9: Maximum Range Rate Error Per Satellite

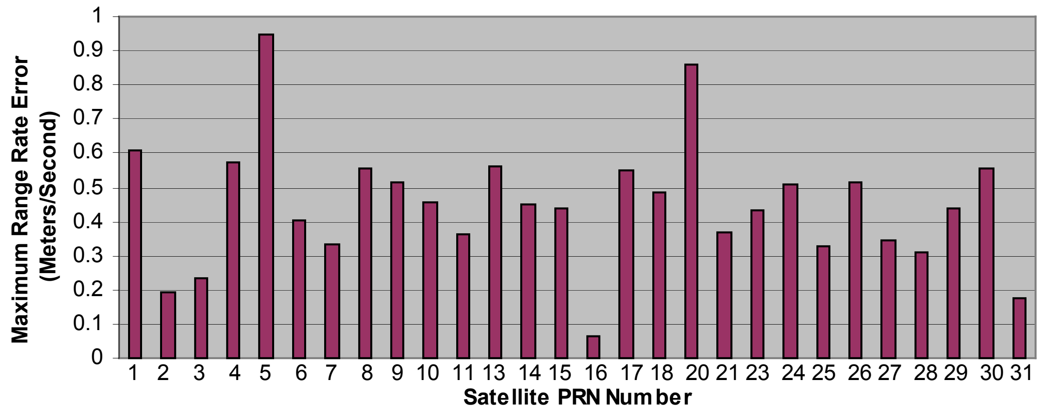
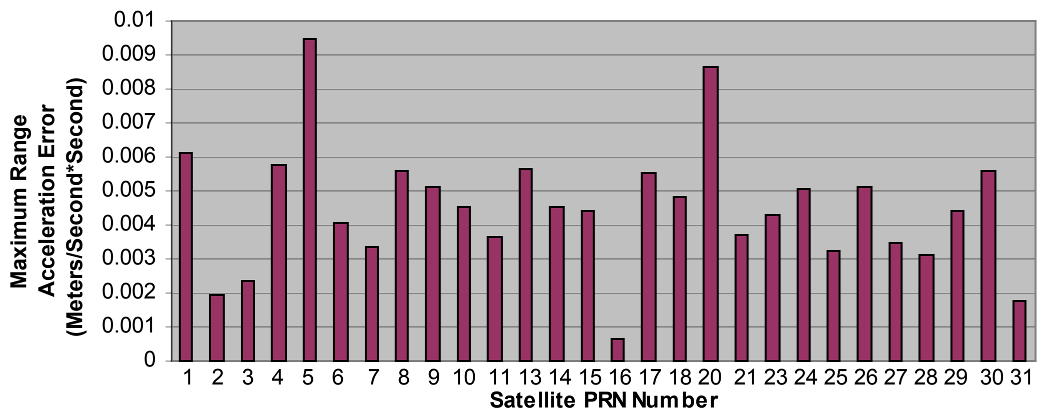


Figure 5-10: Maximum Range Acceleration Per Satellite



6.0 Solar Storms

Solar storm activity is being monitored in order to assess the possible impact on GPS SPS performance. Solar activity is reported by the Space Environment Center (SEC) , a division of the National Oceanic and Atmospheric Administration (NOAA). When storm activity is indicated, ionospheric delays of the GPS signal, satellite outages, position accuracy and availability will be analyzed.

The following article was taken from the SEC web site http://sec.noaa.gov. It briefly explains some of the ideas behind the association of the aurora with geomagnetic activity and a bit about how the ‘K-index’ or ‘K-factor’ works.

> *The aurora is caused by the interaction of high-energy particles (usually electrons) with neutral atoms in the earth's upper atmosphere. These high-energy particles can ‘excite’ (by collisions) valence electrons that are bound to the neutral atom. The ‘excited’ electron can then ‘de-excite’ and return back to its initial, lower energy state, but in the process it releases a photon (a light particle). The combined effect of many photons being released from many atoms results in the aurora display that you see.*
>
> *The details of how high energy particles are generated during geomagnetic storms constitute an entire discipline of space science in its own right. The basic idea, however, is that the Earth’s magnetic field (let us say the ‘geomagnetic field’) is responding to an outwardly propagating disturbance from the Sun. As the geomagnetic field adjusts to this disturbance, various components of the Earth’s field change form, releasing magnetic energy and thereby accelerating charged particles to high energies. These particles, being charged, are forced to stream along the geomagnetic field lines. Some end up in the upper part of the earth’s neutral atmosphere and the auroral mechanism begins.*
>
> *An instrument called a magnetometer may also measure the disturbance of the geomagnetic field. At NOAA’s operations center magnetometer data is received from dozens of observatories in one-minute intervals. The data is received at or near to ‘real-time’ and allows NOAA to keep track of the current state of the geomagnetic conditions. In order to reduce the amount of data NOAA converts the magnetometer data into three-hourly indices, which give a quantitative, but less detailed measure of the level of geomagnetic activity. The K-index scale has a range from 0 to 9 and is directly related to the maximum amount of fluctuation (relative to a quiet day) in the geomagnetic field over a three-hour interval.*
>
> *The K-index is therefore updated every three hours. The K-index is also necessarily tied to a specific geomagnetic observatory. For locations where there are no observatories, one can only estimate what the local K-index would be by looking at data from the nearest observatory, but this would be subject to some errors from time to time because geomagnetic activity is not always spatially homogenous.*
>
> *Another item of interest is that the location of the aurora usually changes geomagnetic latitude as the intensity of the geomagnetic storm changes. The location of the aurora often takes on an ‘oval-like’ shape and is appropriately called the auroral oval.*

Figures 6-1 through 6-3 show the K-index for three time periods with significant solar activity. Although there were other days with increased solar activity, these time periods were selected as examples. (See Appendix B for the actual geomagnetic data for this reporting period.)

Figure 6-1 K-Index for 28-30 May 2003

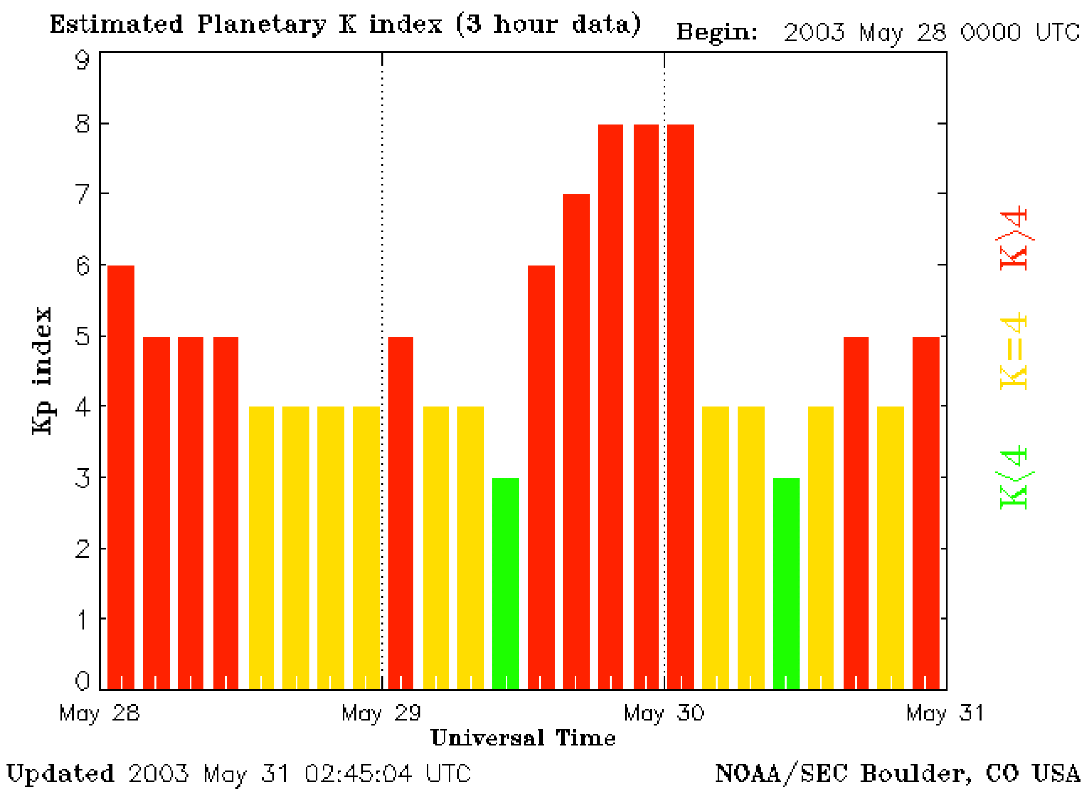


Figure 6-2 K-Index for 16-18 June 2003

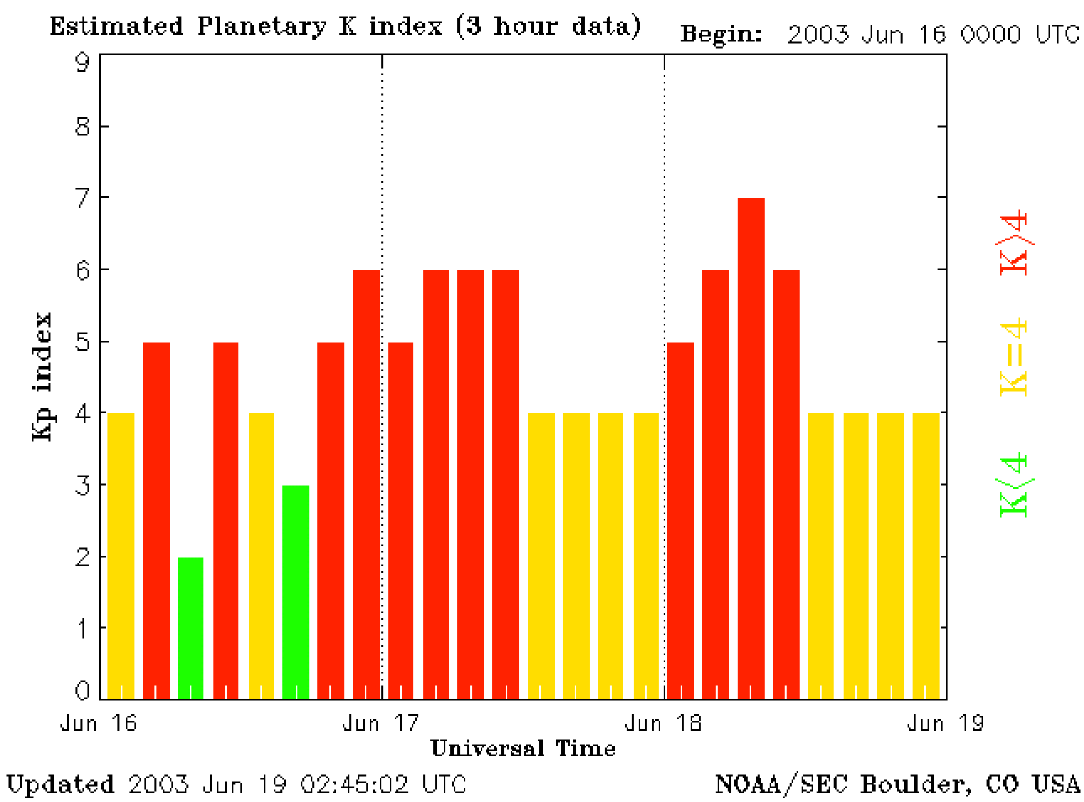
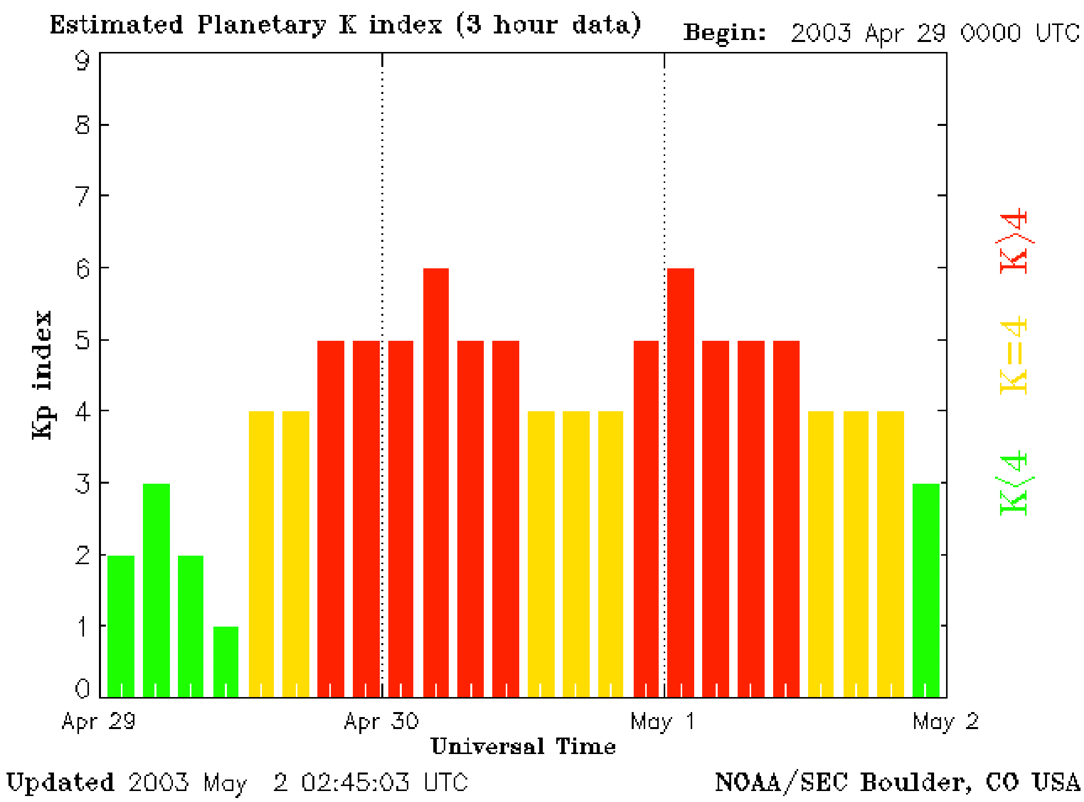


Figure 6-3 K-Index for 29 April - 1 May 2003



Tables 6-1 and 6-2 below show the PDOP and position accuracy information, respectively, for the days corresponding to Figure 6-1. The GPS SPS performance met the availability requirements during all storms that occurred during this quarter.

Table 6-1 PDOP Statistics for 29 May 2003

NSTB/WAAS Site	Min PDOP	Max PDOP	Mean PDOP	99.99% PDOP	99.99% VDOP
Atlantic City	1.248	5.881	1.844	5.647	3.821
Columbus	1.199	3.535	1.839	3.532	3.059
Denver	1.198	3.103	1.847	3.103	2.652
Grand Forks	1.302	3.794	1.843	3.789	3.202
Greenwood	1.281	4.667	1.837	4.664	4.137
Prescott	1.281	5.999	2.242	5.981	5.714
Billings	1.208	3.009	1.800	3.009	2.628
Anchorage	1.202	4.362	1.827	4.360	3.968
Chicago	1.263	5.113	1.769	5.109	4.228
Kansas City	1.183	4.560	1.794	3.117	2.466
Salt Lake City	1.231	5.249	1.838	5.229	4.817
Miami	1.326	3.352	1.799	3.352	3.075
Atlanta	1.241	4.651	1.829	4.651	4.255

Table 6-2 Horizontal & Vertical Accuracy Statistics for 29 May 2003

NSTB Site	95% Horizontal (Meters)	95% Vertical (Meters)	99.99% Horizontal (Meters)	99.99% Vertical (Meters)
Atlantic City	10.112	9.928	11.577	14.456
Columbus	5.432	7.842	17.787	16.737
Denver	4.836	6.419	10.755	10.341
Grand Forks	6.020	7.426	14.157	11.549
Greenwood	5.719	10.255	13.741	21.660
Prescott	5.938	10.745	7.810	24.549
Billings	4.613	6.110	12.289	10.011
Anchorage	3.079	6.132	5.756	12.495
Chicago	8.059	9.617	12.763	11.526
Kansas City	7.138	8.229	19.770	15.816
Salt Lake City	5.272	5.316	7.955	17.346
Miami	5.874	16.072	9.535	21.699
Atlanta	8.937	11.540	14.388	20.169

APPENDICES A – D

Conditions and Constraints	***Coverage Standard***	***Measured Performance***
• Probability of 4 or more satellites in view over any 24 hour interval, averaged over the globe • 4 satellites must provide PDOP of 6 or less • 5° mask angle with no obscura • Standard is predicated on 24 operational satellites, as the constellation is defined in the almanac	≥ 99.9% global average	99.978%
• Probability of 4 or more satellites in view over any 24 hour interval, for the worst-case point on the globe • 4 satellites must provide PDOP of 6 or less • 5° mask angle with no obscura • Standard is predicated on 24 operational satellites, as the constellation is defined in the almanac	≥ 96.9% at worst-case point	98.542% Availability 99.9% PDOP was 3.850
Conditions and Constraints	***Satellite Availability Standard***	***Measured Performance***
• Conditioned on coverage standard • Standard based on a typical 24 hour interval, averaged over the globe • Typical 24 hour interval defined using averaging period of 30 days	≥ 99.85% global average	100%
• Conditioned on coverage standard • Standard based on a typical 24 hour interval, for the worst-case point on the globe • Typical 24 hour interval defined using averaging period of 30 days	≥ 99.16% single point average	99.998%
• Conditioned on coverage standard • Standard represents a worst-case 24 hour interval, averaged over the globe	≥ 95.87% global average on worst-case day	99.984%
• Conditioned on coverage standard • Standard based on a worst-case 24 hour interval, for the worst-case point on the globe	≥ 83.92% at worst-case point on worst-case day	99.789%
Conditions and Constraints	***Service Reliability Standard***	***Measured Performance***
• Conditioned on coverage and service availability standards • 500 meter NTE predictable horizontal error reliability threshold • Standard based on a measurement interval of one year; average of daily values over the globe • Standard predicated on a maximum of 18 hours of major service failure behavior over the sample interval	≥ 99.97% global average	100%
• Conditioned on coverage and service availability standards • 500 meter Not-to-Exceed (NTE) predictable horizontal error reliability threshold • Standard based on a measurement interval of one year; average of daily values from the worst-case point on the globe • Standard based on a maximum of 18 hours of major service failure behavior over the sample interval	≥ 99.79% single point average	100%
Conditions and Constraints	***Accuracy Standard***	***Measured Performance***

• Conditioned on coverage, service availability and service reliability standards • Standard based on a measurement interval of 24 hours, for any point on the globe	<u>Predictable Accuracy</u> ≤ 100 m horz. error 95% of time ≤ 156 m vert. error 95% of time ≤ 300 m horz. error 99.99% of time ≤ 500 m vert. error 99.99% of time	≤5.608m HE 95% ≤20.098m HE 99.99% ≤10.437m VE 95% ≤24.749m VE 99.99%
• Conditioned on coverage, service availability and service reliability standards • Standard based on a measurement interval of 24 hours, for any point on the globe	<u>Repeatable Accuracy</u> ≤ 141 m horz. error 95% of time ≤ 221 m vert. error 95% of time	≤2.187m HE 95% ≤6.165m VE 95%
• Conditioned on coverage, service availability and service reliability standards • Standard based on a measurement interval of 24 hours, for any point on the globe • Standard presumes that the receivers base their position solutions on the same satellites, with position solutions computed at approximately the same time	<u>Relative Accuracy</u> ≤ 1.0 m horz. error 95% of time ≤ 1.5 m vert. error 95% of time	Future Reports
• Conditioned on coverage, service availability and service reliability standards • Standard based upon SPS receiver time as computed using the output of the position solution • Standard based on a measurement interval of 24 hours, for any point on the globe • Standard is defined with respect to Universal Coordinated Time, as it is maintained by the United States Naval Observatory	<u>Time Transfer Accuracy</u> ≤ 340 nanoseconds time transfer error 95% of time	≤23 ns 95% of the time
• Conditioned on satellite indicating healthy status • Standard based on a measurement interval of 24 hours, for any point on the globe • Standard restricted to range domain errors allocated to space/control segments • Standards are not constellation values -- each satellite is required to meet the standards • Assessment requires minimum of four hours of data over the 24 hour period for a satellite in order to evaluate that satellite against the standard	<u>Range Domain Accuracy</u> ≤ 150 m NTE range error ≤ 2 m/s NTE range rate error ≤ 19 mm/s^2 NTE range acceleration error ≤ 8 mm/s^2 range acceleration error 95% of time	34.361m NTE Range Error 0.94641m/s NTE Rate Error 9.50mm/s^2 NTE Accl. Error ≤8mm/s^2 99.999% of the time

```
#  Prepared by the U.S. Dept. of Commerce, NOAA, Space Environment Center.
#  Please send comment and suggestions to sec@sec.noaa.gov
#
#             Current Quarter Daily Geomagnetic Data
#

                Middle Latitude        High Latitude            Estimated
              - Fredericksburg -     ---- College ----       --- Planetary ---
   Date        A     K-indices        A     K-indices        A     K-indices
2003 04 01    11   4 2 1 2 2 3 3 2   -1 -1 3 2 5 3 4 5 2    12   5 4 1 3 2 3 3 3
2003 04 02    11   2 3 3 2 3 2 2 3   42  3 3 6 6 6 4 4 3    20   2 4 4 4 4 3 3 4
2003 04 03    11   2 2 3 2 2 2 2 4   15  3 3 3 3 3 3 3 3    14   3 2 3 3 3 3 3 4
2003 04 04    13   3 2 3 3 3 2 3 3   57  6 3 6 6 6 6 3 4    26   4 3 5 5 5 3 4 4
2003 04 05    16   4 4 2 2 3 3 3 3   35  4 4 3 4 6 5 5 2    23   5 4 3 3 4 4 4 4
2003 04 06     6   2 3 2 1 1 2 1 1   10  3 2 2 4 1 3 1 0     9   3 3 2 2 2 3 3 1
2003 04 07     4   1 0 0 2 2 2 1 1    9  1 0 0 4 4 3 0 0     6   2 1 1 2 3 3 1 1
2003 04 08    17   4 3 3 4 4 3 1 2   36  3 3 4 6 6 5 3 2    20   2 3 4 5 4 4 2 3
2003 04 09    14   4 2 4 3 3 2 2 2   41  3 4 6 6 6 4 3 2    25   4 3 5 4 5 3 3 2
2003 04 10    17   2 4 3 3 4 3 3 3   30  3 5 5 5 4 4 3 3    26   3 5 5 5 3 3 4 3
2003 04 11    13   3 3 2 2 2 2 3 4   22  3 3 2 5 3 5 3 3    14   3 3 2 3 3 3 3 3
2003 04 12     7   3 2 1 1 2 2 1 2   11  3 1 1 3 4 3 1 1     7   3 2 2 2 3 2 2 2
2003 04 13     8   3 3 2 2 2 1 1 2   13  2 2 2 4 5 1 1 1    10   3 3 2 2 3 2 2 2
2003 04 14    13   3 3 2 2 2 2 3 4   22  3 3 2 5 3 5 3 3    16   2 3 1 2 5 4 3 3
2003 04 15    13   3 3 2 2 2 2 3 4   34  3 4 4 7 5 1 2 2    22   4 4 4 5 4 2 2 3
2003 04 16    13   3 3 2 2 2 2 3 4   54  5 3 5 7 5 6 4 4    31   4 3 4 6 3 3 5 4
2003 04 17    20   3 4 4 4 3 4 3 2   50  3 5 6 6 6 6 3 2    30   3 5 5 5 4 5 3 3
2003 04 18    18   1 4 4 3 4 3 3 3   27  2 3 4 6 5 4 2 2    20   2 5 4 4 4 3 3 3
2003 04 19    10   3 2 3 2 2 2 2 3   -1  2 2 1-1 3 2 2 2    18   3 3 3 0 3 3 2 3
2003 04 20    12   3 3 2 2 2 2 3 4   16  3 4 4 3 2 3 3 2    16   4 4 4 2 3 3 2 4
2003 04 21    12   3 3 2 2 2 2 3 4   48  6 5 6 6 3 5 4 2    21   4 4 5 4 3 3 3 3
2003 04 22    13   3 3 2 2 2 2 3 4   30  3 4 5 5 5 4 3 3    22   4 4 4 4 3 3 3 4
2003 04 23    13   3 4 2 3 2 2 3 2   30  3 4 5 5 5 4 3 3    18   2 4 5 4 3 3 3 3
2003 04 24    24   3 2 4 3 4 4 4 5   38  3 3 4 5 6 6 4 3    24   3 3 4 5 4 4 4 4
2003 04 25    19   4 4 3 3 2 4 2 4   -1  4 4-1-1-1-1 2 3    32   4 5 5 5 3 4 3 5
2003 04 26     9   2 2 3 2 2 2 3 2   21  4 3 5 3 3 4 3 2    15   4 2 4 2 3 3 3 3
2003 04 27    11   3 3 2 2 2 2 3 3   18  3 3 3 4 4 4 2 2    15   3 4 3 3 3 4 3 3
2003 04 28     9   2 3 3 3 2 1 1 2   29  3 6 4 6 3 2 1 1    20   3 5 4 5 3 3 2 2
2003 04 29    13   2 2 1 0 3 3 4 4   39  2 2 2 0 6 6 6 5    20   2 3 2 1 4 4 5 5
2003 04 30    34   6 6 3 3 3 3 4 4   43  5 5 6 5 4 5 4 3    40   5 6 5 5 4 4 4 5
2003 05 01    29   6 5 4 3 3 3 3 3   48  5 5 6 6 5 5 3 3    40   6 5 5 5 4 4 4 3
2003 05 02    11   2 5 2 2 2 1 1 2   24  4 5 3 5 4 3 1 2    17   3 5 3 3 3 2 2 3
2003 05 03     7   2 3 1 2 2 2 1 2   14  2 3 3 4 4 3 1 1    10   2 3 3 3 2 2 2 2
2003 05 04     4   2 2 0 2 1 1 1 1   10  3 2 2 4 2 2 1 1     7   3 2 1 2 2 2 2 2
2003 05 05    11   1 2 2 2 2 4 3 3   13  1 2 1 3 3 4 3 3    12   2 2 1 2 2 4 4 4
2003 05 06    15   3 2 2 2 4 3 3 4   40  3 3 2 6 6 6 4 3    23   4 3 3 4 5 4 4 4
2003 05 07    24   5 4 5 3 3 3 3 2   61  4 5 7 7 5 5 4 2    36   5 5 6 5 4 4 3 3
2003 05 08    22   4 4 3 3 4 4 4 3   50  4 4 5 7 5 5 5 3    30   5 5 4 5 4 4 5 3
2003 05 09    20   4 4 4 3 4 3 2 3   46  3 4 5 7 6 5 2 2    29   4 4 5 5 5 3 3 3
2003 05 10    32   6 6 4 4 2 2 3 3   -1  5 6 6 6 1-1-1-1    43   6 6 6 5 2 3 3 3
2003 05 11    22   4 2 5 4 4 3 2 3   37  4 2 5 6 6 4 3 3    31   5 3 6 5 5 3 3 3
2003 05 12    14   3 4 3 2 2 2 3 3   23  3 3 4 5 5 3 2 2    18   3 4 4 3 4 3 3 3
2003 05 13    24   4 3 3 3 4 5 3 4   41  3 3 5 6 6 5 4 3    27   4 3 4 5 4 4 4 4
2003 05 14    17   4 3 3 3 3 3 3 3   42  4 5 6 5 5 5 4 2    27   5 5 5 4 3 4 4 3
2003 05 15    19   3 4 4 2 3 4 3 3   44  3 4 6 6 6 5 3 2    23   4 4 4 4 4 4 3 3
2003 05 16     9   3 1 2 2 2 1 3 3   10  2 2 3 3 3 2 2 2     9   3 2 2 2 2 2 3 3
2003 05 17     6   2 3 2 1 1 1 2 1   16  2 3 3 4 5 2 1 1     9   3 3 3 2 3 2 1 1
2003 05 18     7   2 2 2 1 1 1 2 3    8  1 3 3 1 1 2 2 2    10   2 2 2 2 3 3 3 3
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2003 05 22    15   4 4 3 2 3 2 3 2   45  4 5 4 5 7 5 3 2    25   5 5 4 3 4 4 3 2
2003 05 23    18   3 3 3 4 3 4 3 3   41  3 5 5 7 4 4 3 2    21   3 4 4 5 3 4 3 3
2003 05 24    14   2 3 4 2 3 2 3 3   33  2 5 5 4 6 4 3 3    22   3 5 5 3 4 3 4 3
2003 05 25    14   4 4 3 2 2 2 2 3   26  4 4 4 5 2 5 3 2    22   5 5 4 3 2 4 3 4
2003 05 26    13   4 2 3 2 3 2 2 3   23  5 3 5 4 3 2 2 3    18   4 3 4 3 3 3 3 4
2003 05 27    18   3 4 2 3 3 2 4 4   27  4 4 2 5 5 3 4 3    26   4 4 3 3 4 3 4 5
2003 05 28    22   5 4 4 3 3 3 3 3   52  5 5 6 6 5 6 3 3    36   6 5 5 5 4 4 4 4
2003 05 29    59   4 3 3 2 5 6 7 7  127  4 4 6 6 8 8 8 6    89   5 4 4 3 6 7 8 8
```

2003 05 30	36	7	4	3	2	3	4	4	4	41	7	4	3	4	4	5	3	4	49	8	4	4	3	4	5	4	5
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2003 06 01	18	2	4	3	2	3	3	4	4	21	3	4	4	3	4	3	4	3	19	3	3	3	2	3	3	4	4
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2003 06 04	13	3	2	2	3	3	3	3	3	37	4	3	3	6	6	5	3	3	21	4	3	3	4	4	4	4	3
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2003 06 08	21	3	4	3	3	3	4	4	4	44	4	5	6	4	5	6	3	4	27	4	5	4	3	3	4	4	4
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2003 06 28	30	3	4	3	6	4	3	3	5	46	3	5	3	7	5	5	4	4	32	3	5	3	6	5	4	4	4
2003 06 29	14	4	3	3	3	3	3	3	3	39	4	4	6	5	5	5	3	3	26	4	3	5	5	4	3	4	4
2003 06 30	14	3	3	4	3	2	2	3	2	41	4	5	7	4	5	4	2	2	20	4	4	5	4	3	3	3	3

Background:

In 1993, the FAA began monitoring and analyzing Global Positioning System (GPS) Standard Positioning Service (SPS) performance data. At present, the FAA has approved GPS for IFR and is developing WAAS and LAAS, both of which are GPS augmentation systems. In order to ensure the safe and effective use of GPS and its augmentation systems within the NAS, it is critical that characteristics of GPS performance as well as specific causes for service outages be monitored and understood. To accomplish this objective, GPS SPS performance data is documented in a quarterly GPS Performance Analysis (PAN) report. The PAN report contains data collected at various National Satellite Test Bed (NSTB) and Wide Area Augmentation System (WAAS) reference station locations. This PAN Problem Report will be issued only when the performance data fails to meet the GPS Standard Positioning Service (SPS) Signal Specification.

Problem Description:

Although no GPS failures were evident in the statistics of this report, there were two GPS satellite failures this quarter. The failures were not recognized in our data collection because range analysis is performed for only one receiver (Atlantic City) for the purposes of this report. On both occasions of failures, the failing satellites were not in view at our data collection site. Analysis has been performed on the events from other means available to us on location and the event summaries are provided here.

Summary of PRN 5 Clock Anomaly Observations: June 11, 2003 (Week 1223 Day3)

PRN 5 experienced what appeared to be a ramp clock error starting approximately second-of-week 329500 and extending thru 332390, growing to a maximum magnitude of about 30 meters. The satellite was visible to the Southeast United States and Caribbean. (The DoD switched the satellite to unhealthy at time 332390).

Impact on SPS mode and SPS Performance.

Figure 1 shows the horizontal position error for San Juan, Puerto Rico WAAS Reference Station, under three conditions (1) PRN 5 in the SPS, L1/L2 solution, (2) PRN 5 excluded from the SPS L1/L2, solution, and the (3) WAAS NPA solution (which includes all WAAS corrections except Ionosphere). The Horizontal Position error is seen to grow to a maximum of 7-8 meters when PRN 5 is included in the SPS, L1/L2 solution. When PRN 5 is excluded from the computations, the horizontal position error at this site in this same mode never exceeds approximately 4 meters.

Figure 2 shows the range error to PRN 5 (red line); the range error grows to a maximum of about 25 - 30 meters.

The overall affect on position performance was small, and within NPA requirements. The measured range error was smaller than the levels of SA typically experienced (as was the case for PRN 27 clock anomaly a few weeks before).

Impact on WAAS and PA performance.

Figures 1 and 2 indicate several things:

1) At the beginning of the plot window of Figure 2 until time 330740, PRN 5 was “not monitored” by WAAS (as was normal for WAAS since PRN 5 wasn’t in view from enough WAAS reference stations);
2) From the time when the satellite UDRE did drop to 50, then 15 meters, the total WAAS correction matched the observed range error (from San Juan, shown in Figure 2, where PRN 5 was excluded from the computations). The PRN 5 clock error grew to about 25 meters, and WAAS corrected for this error until the satellite was declared “Do Not Use”, at 332399.

3) The resulting NPA position error at San Jaun WRS in PA mode (Figure 1, green marks) shows the typical WAAS error (less then 2 -3 meters), throughout the PRN 5 anomaly.

Conclusions:

The PRN5 anomaly appeared to be a clock ramp (with a change in direction) from about 329500 until 332390. The magnitude of the anomaly was less than SA had been in the past.

WAAS detected the clock error and provided appropriate corrections, until the satellite was switched to Unhealthy (time 332390), at which time the WAAS declared PRN 5 "Do Not Use" with an alert (beginning at 332399). WAAS appeared to work perfectly during this anomaly.

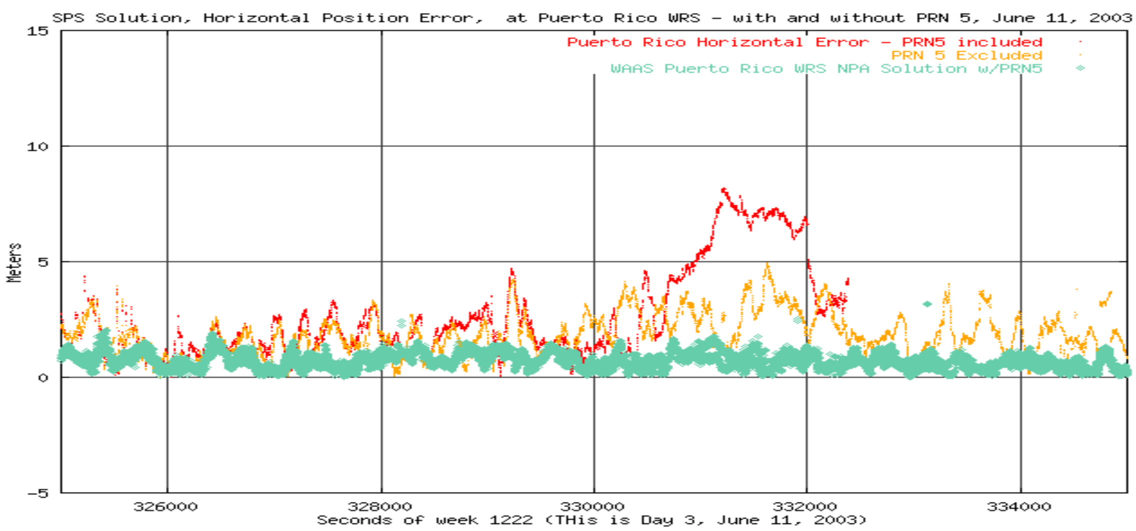

Figure 1: San Juan, Puerto Rico, WRS Horizontal Position (SPS w L1/L2)

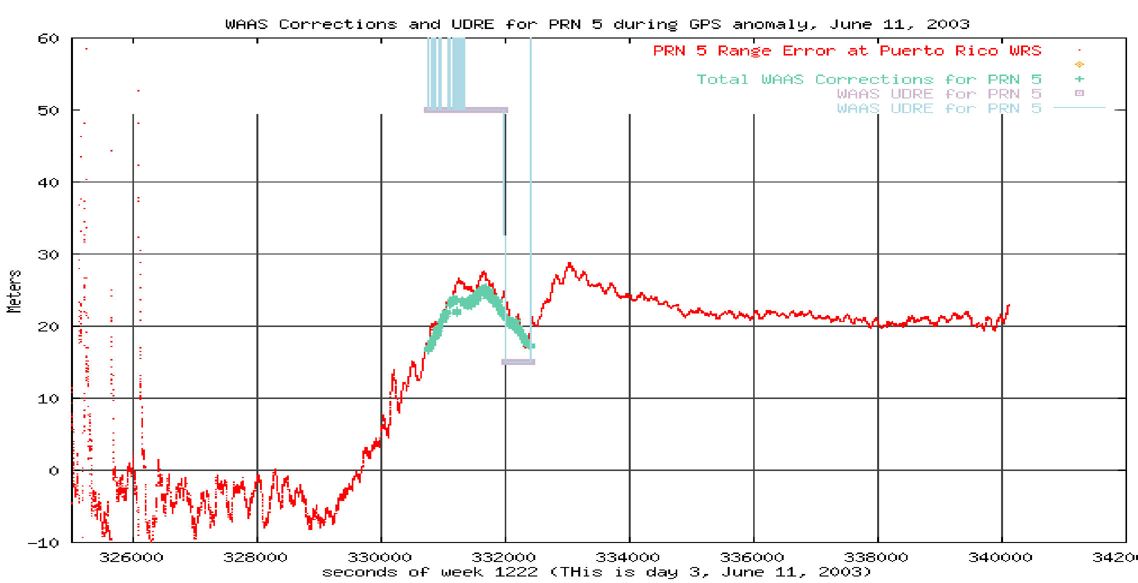

Figure 2: San Juan, Puerto Rico, WRS Data: PRN 5 range error and WAAS correction

Summary of PRN 27 Clock Error Observations: May 26, 2003 (Week 1220 Day1)

PRN 27 experienced what appeared to be a ramp clock error starting approximately second-of-week 144000 and extending thru 149000, growing to a magnitude of about 38 meters by that time. The satellite was visible to the northeast United States and eastern Canada. The DoD switched the satellite to unhealthy at time 149669.

Impact on SPS mode and SPS Performance.

Figure 1 shows the horizontal position error and PRN 27 range error results from the Gander, Canada, TRS. The Horizontal Position error is seen to grow to approximately 10-15 meters when PRN 27 is included in the computations, and the PRN 27 range error grows to about 30 meters, by the time the satellite is switched to "Unhealthy". When PRN 27 is excluded from the computations, the horizontal position error at this time never exceeds approximately 4 meters, and the PRN 27 range error grows to approximately 38 meters. The difference between the range error results is due to the fact that when a satellite is included in the position computation, it also affects the TRS clock computation, which in turn is used to compute the range error. By excluding PRN 27 in the position computation, we can see the true range error to PRN 27.

The overall affect on position performance was small, and within NPA requirements. The measured range error was smaller than the levels of SA typically experienced (back in the days when SA was on).

Impact on WAAS and PA performance.

Figure 2 shows several things:

4) PRN 27 was "not monitored" (UDRE = 175 on this scale) at the beginning of the anomaly (abut time 144000), because the satellite was not in view of enough WAAS WRSs.
5) At times when the satellite UDRE did drop to 50 meters, the total clock correction (fast clock + slow clock), matched the observed range error (from Gander, shown in Figure 1, when PRN 27 was excluded from the computations). This means that WAAS correctly measured and corrected for the clock error of PRN 27.
6) The resulting position error at Boston WRS in PA mode (orange line) shows the typical error (less then 2 -3 meters, although hard to see at this graph scale), throughout the PRN 27 anomaly.
7) Reprocessing the WRS in SPS mode, and including PRN27 in the computations, shows about a 10 meter horizontal position error (red line), until set unhealthy.

Conclusions:

The PRN27 anomaly appeared to be a clock ramp from about 144000 to 149000. The magnitude of the anomaly was less than SA had been in the past.

WAAS detected the clock error and provided appropriate corrections, until the satellite was switched to Unhealthy, at which time the WAAS declared PRN 27 "Do Not Use". WAAS appeared to work perfectly during this anomaly.

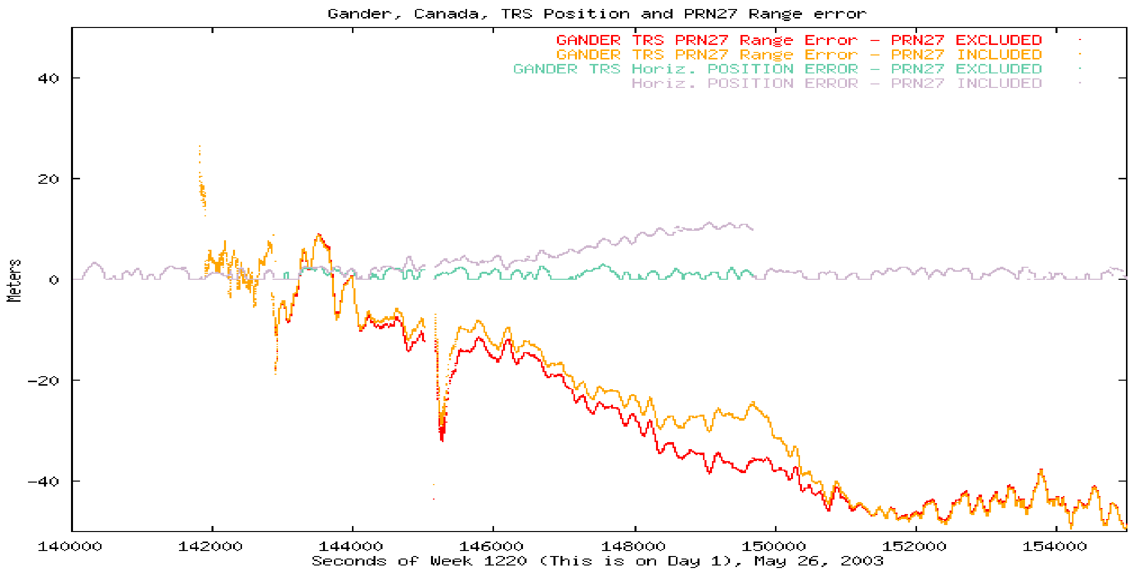

Figure 1: Gander, Canada, TRS Data

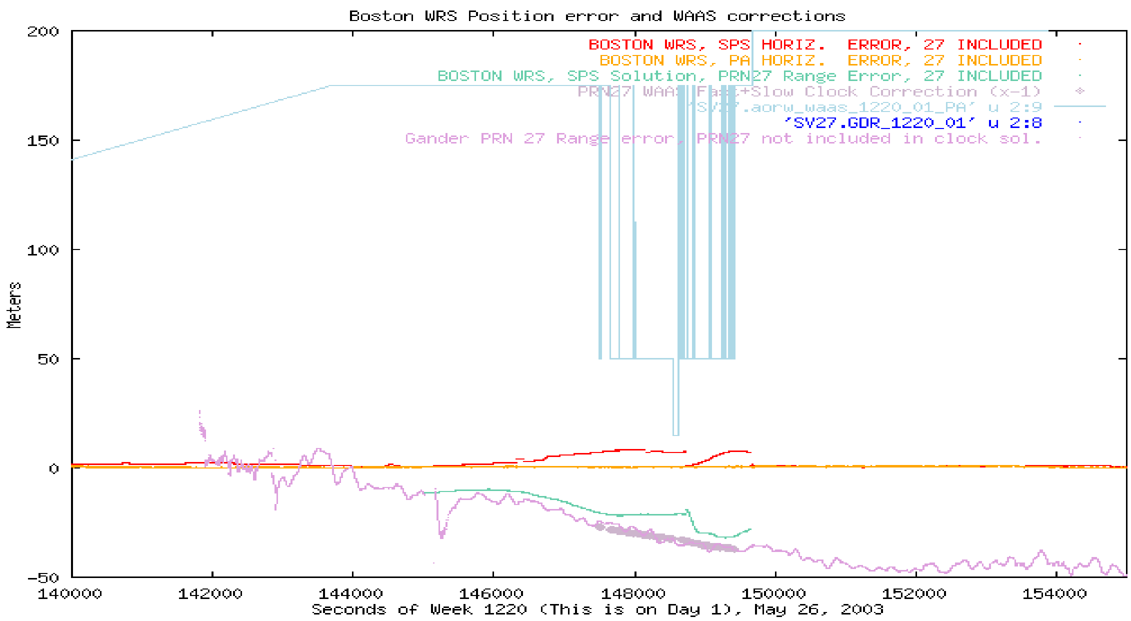

Figure 2: Boston WRS and WAAS Data

The terms and definitions discussed below are taken from the Standard Positioning Service Performance Specification (SPS) (June 2, 1995). An understanding of these terms and definitions is a necessary prerequisite to full understanding of the Signal Specification.

<u>General Terms and Definitions</u>

Block I and Block II Satellites. The Block I is a GPS concept validation satellite; it does not have all of the design features and capabilities of the production model GPS satellite, the Block II. The FOC 24 satellite constellation is defined to consist entirely of Block II/IIA satellites. For the purposes of this Signal Specification, the Block II satellite and a slightly modified version of the Block II known as the Block IIA provide an identical service.

Dilution of Precision (DOP). The magnifying effect on GPS position error induced by mapping GPS ranging errors into position through the position solution. The DOP may be represented in any user local coordinate desired. Examples are HDOP for local horizontal, VDOP for local vertical, PDOP for all three coordinates, and TDOP for time.

Geometric Range. The difference between the estimated locations of a GPS satellite and an SPS receiver.

Major Service Failure. A condition over a time interval during which one or more SPS performance standards are not met and the civil community was not warned in advance.

Minimum SPS Receiver Capabilities. Minimum standards for signal reception and processing capabilities that are incorporated into the design of an SPS receiver. This ensures consistent performance with the SPS performance standards.

Navigation Data. Data provided to the SPS receiver via each satellite's ranging signal, containing the ranging signal time of transmission, the transmitting satellite's orbital elements, an almanac containing abbreviated orbital element information to support satellite selection, ranging measurement correction information, and status flags.

Navigation Message. Message structure designed to carry navigation data.

Operational Satellite. A GPS satellite that is capable of, but may or may not be, transmitting a usable ranging signal. For the purposes of the SPS, any satellite contained within the transmitted navigation message almanac is considered to be an operational satellite.

Position Solution. The use of ranging signal measurements and navigation data from at least four satellites to solve for three position coordinates and a time offset.

Selective Availability. Protection technique employed by the DOD to deny full system accuracy to unauthorized users.

Service Disruption. A condition over a time interval during which one or more SPS performance standards are not supported, but the civil community was warned in advance.

SPS Performance Envelope. The range of variation in specified aspects of SPS performance.

SPS Performance Standard. A quantifiable minimum level for a specified aspect of GPS SPS performance.

Standard Positioning Service (SPS). Three-dimensional position and time determination capability provided to a user equipped with a minimum capability GPS SPS receiver in accordance with GPS national policy and the performance specifications.

SPS Ranging Signal Measurement. The difference between the ranging signal time of reception (as defined by the receiver's clock) and the time of transmission contained within the satellite's navigation data (as defined by the satellite's clock) multiplied by the speed of light. Also known as the *pseudo range*.

SPS Signal, or SPS Ranging Signal. An electromagnetic signal originating from an operational satellite. The SPS ranging signal consists of a Pseudo Random Noise (PRN) Coarse/Acquisition (C/A) code, a timing reference and sufficient data to support the position solution generation process.

Usable SPS Ranging Signal. An SPS ranging signal that can be received, processed and used in a position solution by a receiver with minimum SPS receiver capabilities.

Performance Parameter Definitions

The definitions provided below establish the basis for correct interpretation of the GPS SPS performance standards. The GPS performance parameters contained in the SPS are defined differently than other radio navigation systems in the Federal Radio Navigation Plan. For a more comprehensive treatment of these definitions and their implications on system use, refer to Annex B of the SPS.

Coverage. The percentage of time over a specified time interval that a sufficient number of satellites are above a specified mask angle and provide an acceptable position solution geometry at any point on or near the Earth. The term "near the Earth" means on or within approximately 200 kilometers of the Earth's surface.

Positioning Accuracy. Given reliable service, the percentage of time over a specified time interval that the difference between the measured and expected user position or time is within a specified tolerance at any point on or near the Earth. This general accuracy definition is further refined through the more specific definitions of four different aspects of positioning accuracy:

- **Predictable Accuracy.** Given reliable service, the percentage of time over a specified time interval that the difference between a position measurement and a surveyed benchmark is within a specified tolerance at any point on or near the Earth.

- **Repeatable Accuracy.** Given reliable service, the percentage of time over a specified time interval that the difference between a position measurement taken at one time and a position measurement taken at another time at the same location is within a specified tolerance at any point on or near the Earth.

- **Relative Accuracy.** Given reliable service, the percentage of time over a specified time interval that the difference between two receivers' position estimates taken at the same time is within a specified tolerance at any point on or near the Earth.

- **Time Transfer Accuracy.** Given reliable service, the percentage of time over a specified time interval that the difference between a Universal Coordinated Time (commonly referred to as UTC) time estimate from the position solution and UTC as it is managed by the United States Naval Observatory (USNO) is within a specified tolerance.

Range Domain Accuracy. Range domain accuracy deals with the performance of each satellite's SPS ranging signal. Range domain accuracy is defined in terms of three different aspects:

- **Range Error.** Given reliable service, the percentage of time over a specified time interval that the difference between an SPS ranging signal measurement and the "true" range between the satellite and an SPS user is within a specified tolerance at any point on or near the Earth.

- **Range Rate Error.** Given reliable service, the percentage of time over a specified time interval that the instantaneous rate-of-change of range error is within a specified tolerance at any point on or near the Earth.

- **Range Acceleration Error.** Given reliable service, the percentage of time over a specified time interval that the instantaneous rate-of-change of range rate error is within a specified tolerance at any point on or near the Earth.

Service Availability. Given coverage, the percentage of time over a specified time interval that a sufficient number of satellites are transmitting a usable ranging signal within view of any point on or near the Earth.

Service Reliability. Given service availability, the percentage of time over a specified time interval that the instantaneous predictable horizontal error is maintained within a specified reliability threshold at any point on or near the Earth. Note that service reliability does not take into consideration the reliability characteristics of the SPS receiver or possible signal interference. Service reliability may be used to measure the total number of major failure hours experienced by the satellite constellation over a specified time interval.